Direct Dark Matter Detection Roundup
Current Experimental Technologies

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University of Minnesota

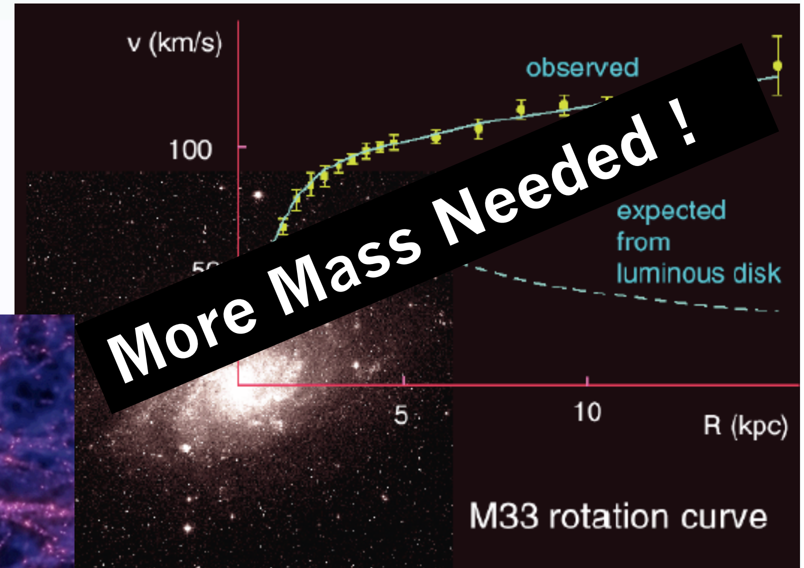
June 10, 2011

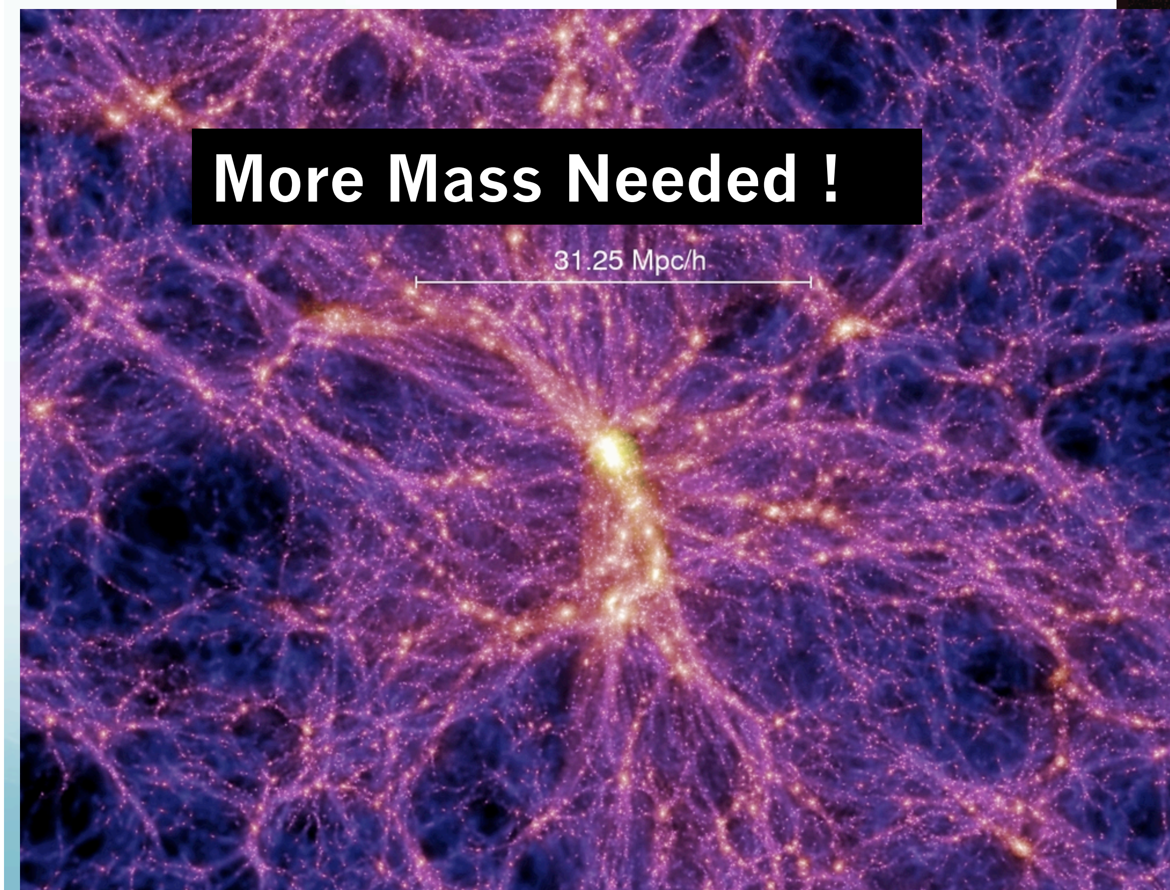
Technology and Instrumentation
in
Particle Physics

The Nature of Dark Matter

The Missing Mass Problem:

Dynamics of stars, galaxies, and clusters
Large Scale Structure formation





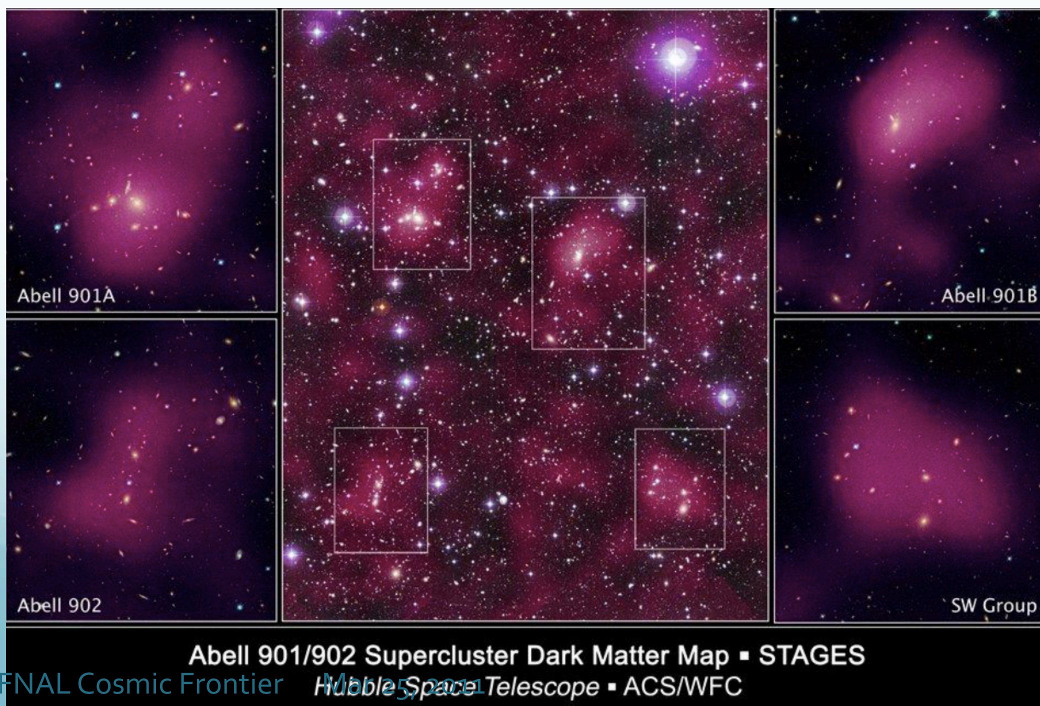
The Nature of Dark Matter

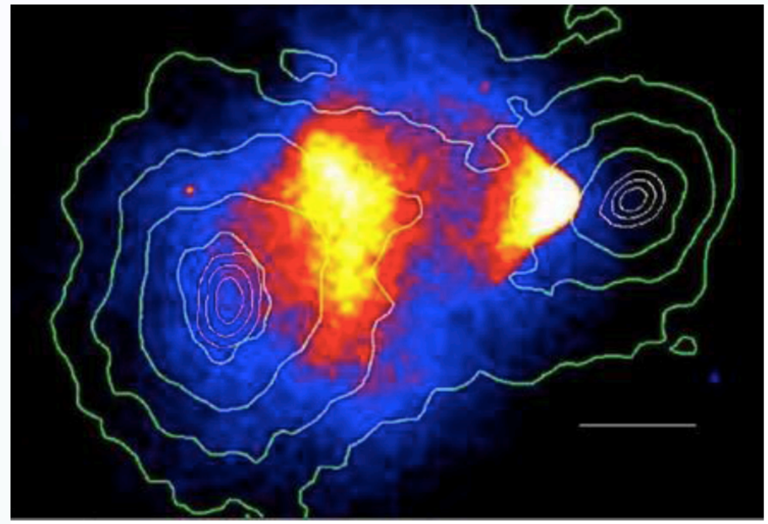
The Missing Mass Problem:

Dynamics of stars, galaxies, and clusters
Large Scale Structure formation

Wealth of evidence for a particle solution

Gravitational Lensing "sees" dark matter
Not enough MACHOs (dark normal stuff!)
Gravity Modification Models unsuccessful





Clowe 2006

Bullet Cluster: Colliding Galaxies

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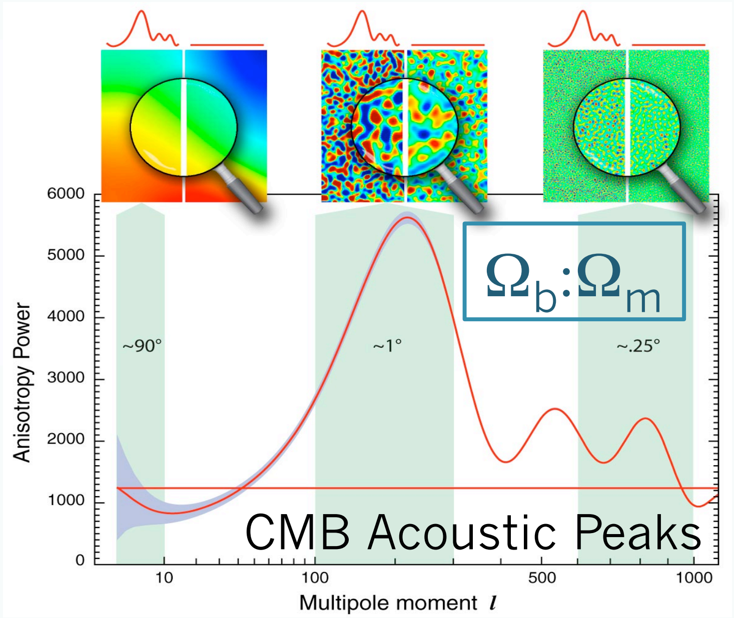
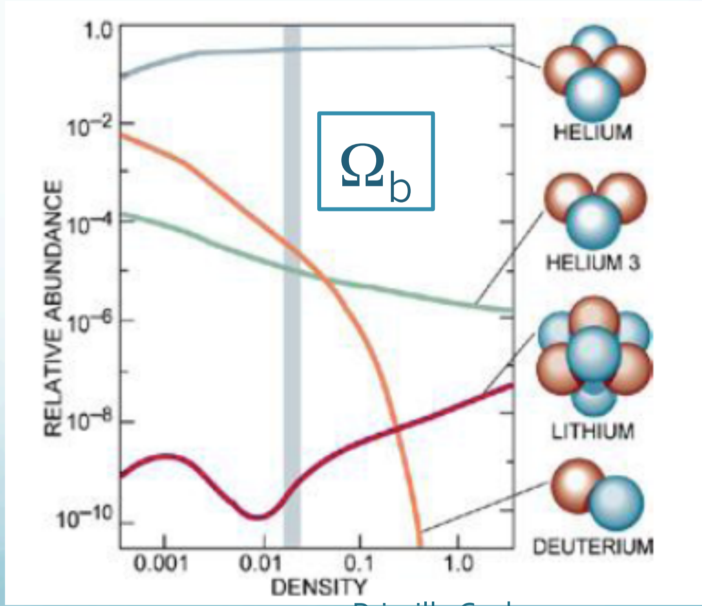


Wealth of evidence for a particle solution

Gravitational Lensing "sees" dark matter
Not enough MACHOs (dark normal stuff!)
Gravity Modification Models unsuccessful

Non-baryonic

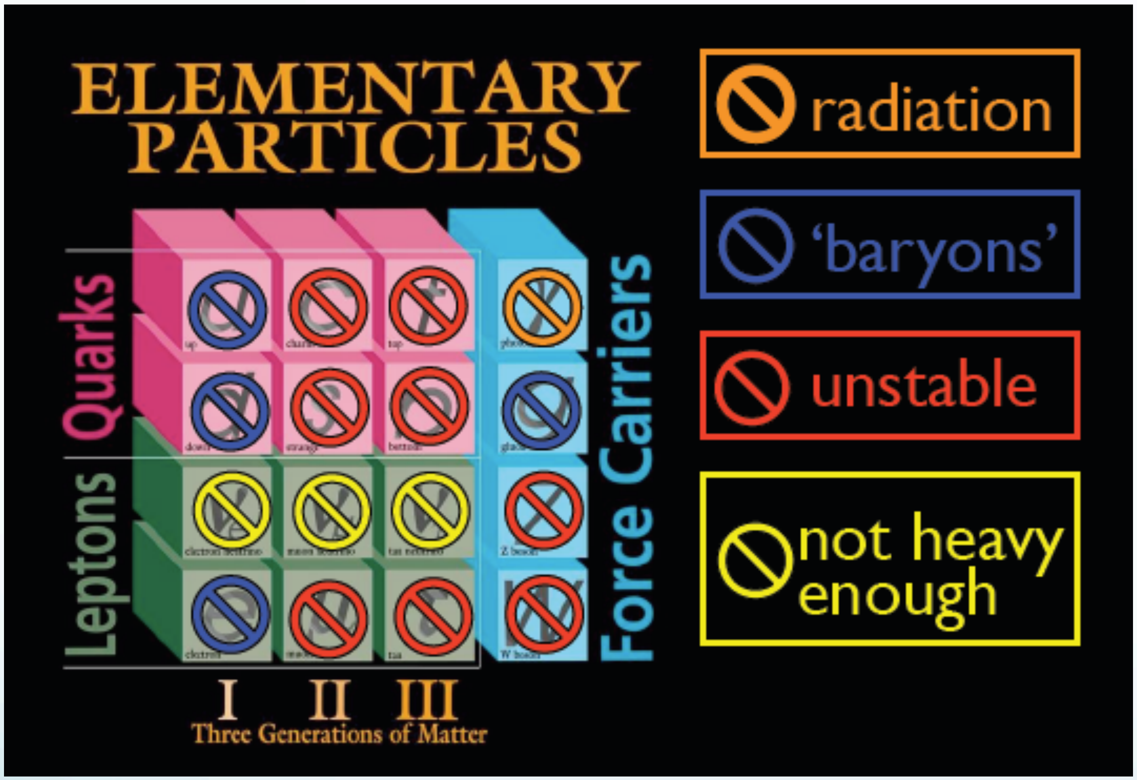
Power spectrum of density fluctuations ➔ Ω_m
Primordial Nucleosynthesis matches Ω_b
Cosmic Microwave Background (CMB)
Height of acoustic peaks ➔ $\Omega_b:\Omega_m$



And STILL HERE!

Stable, neutral, non-relativistic
Interacts via gravity and/or weak force

The Nature of Dark Matter



(Gondolo, DM Crossroads, Desy 2008)

Thus, we have eliminated all known particles!

We have to turn to Theoretical Models to give us a hint of its properties and to suggest strategies for finding it

Dark Matter Candidates

What particles can we imagine?

WIMPs, axions, Wimpzillas, sterile ν's, gravitinos, KK, and much more!

We prefer particles that simultaneously solve another problem

SUSY relics: Solves gauge hierarchy problem: Why is M_{Pl} >> M_{EW}?
KK modes: Solve via extra, compact dimensions (unifies gravity with S,EW)
Axions: Restores CP-symmetry in QCD via new (broken) chiral symmetry,

Don't violate astrophysical observables

e.g. diffuse γ–ray bkgd , etc.

What particle can do all that and ALSO

Match the observed relic density starting from thermodynamic equilibrium in the early Universe?

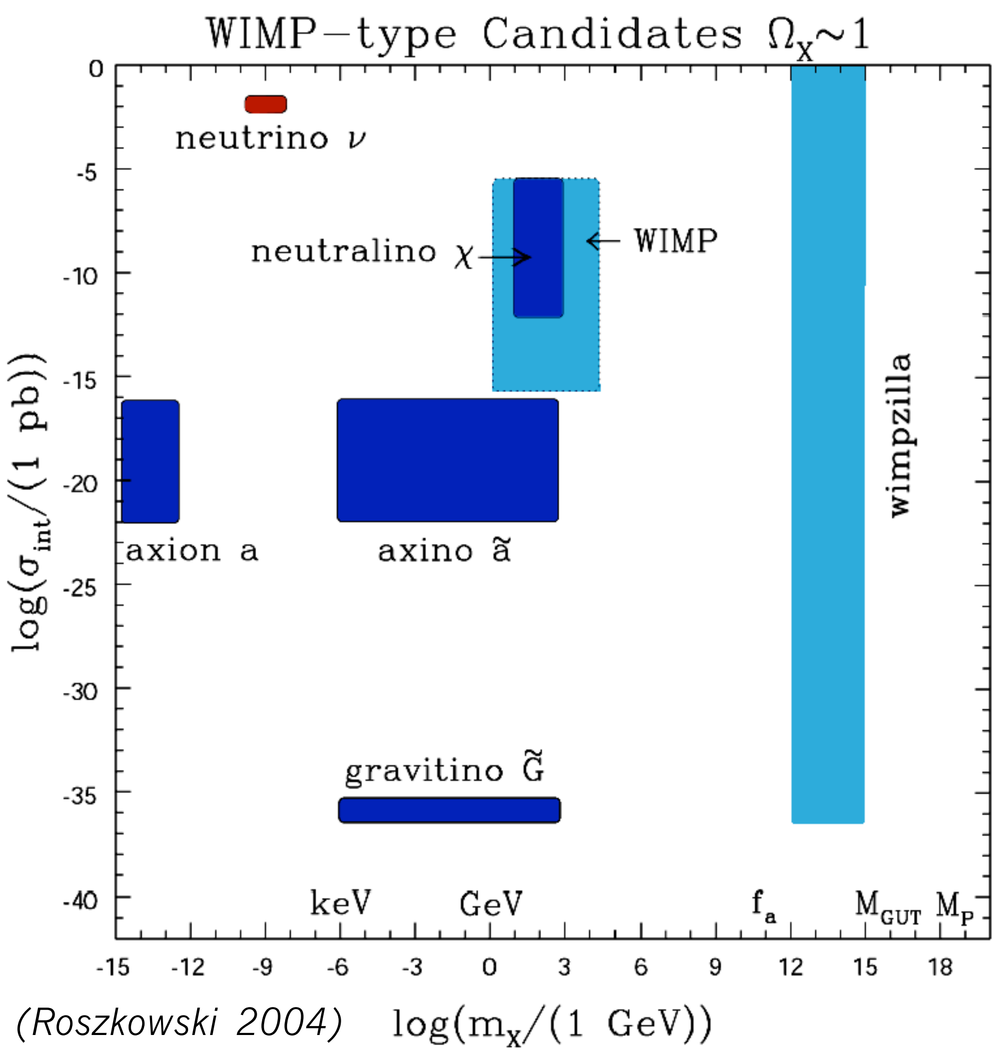
Particles with annihilation cross sections at the Weak Scale !

WIMP

$$\Omega_\chi h^2 = \Omega_{\rm cdm} h^2 \simeq 0.1143$$
$$\text{for } \langle \sigma v \rangle_{\rm ann} \simeq 3 \times 10^{-26} {\rm cm}^3/{\rm s}$$

The Requisite Anti-Hubris Plot

HUGE σ - m space



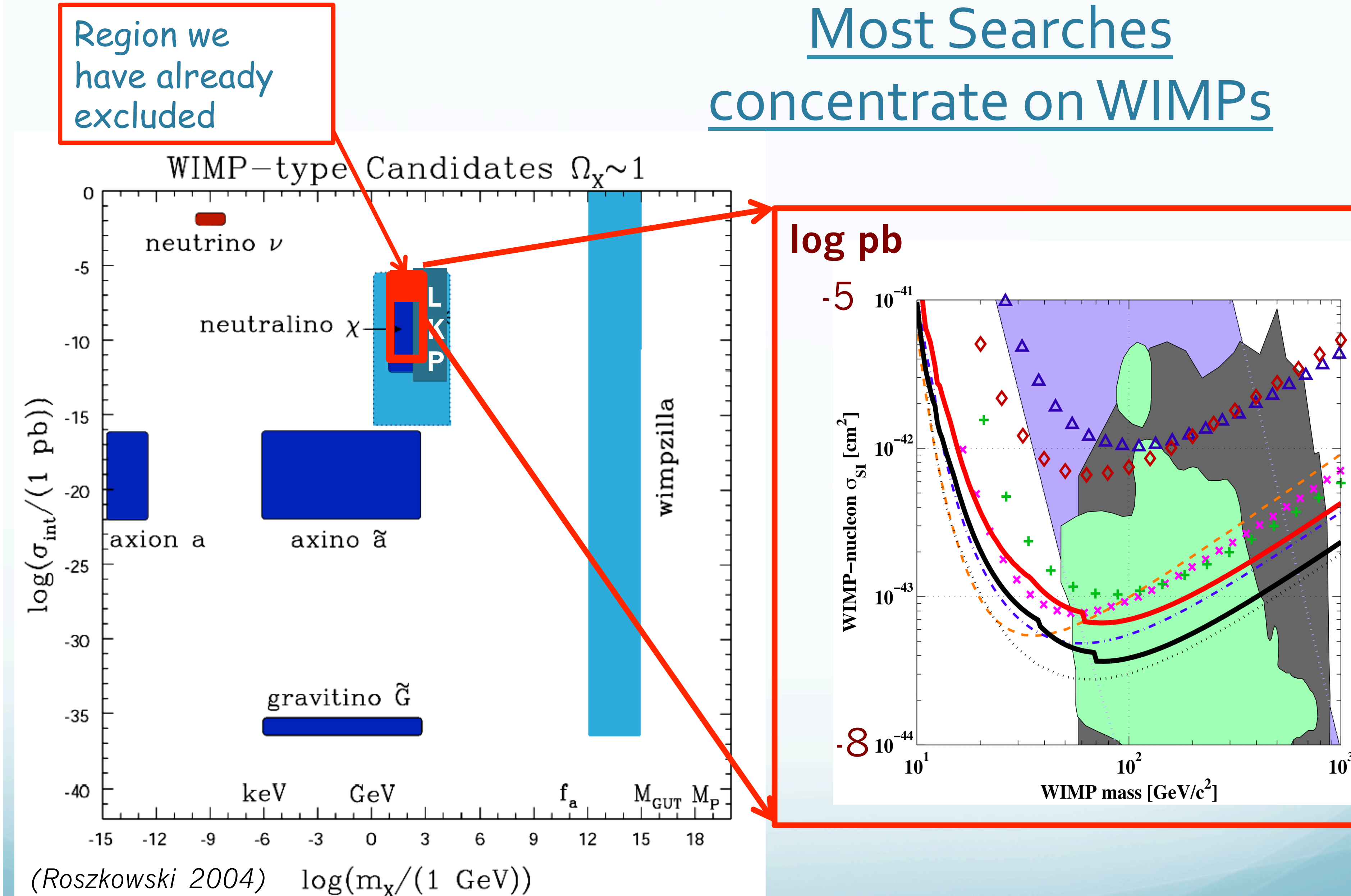
(Roszkowski 2004)

Our Favorite candidate

Weakly Interacting Massive Particle

maybe it's a neutralino
or
a Kaluza-Klein mode

Most Searches concentrate on WIMPs

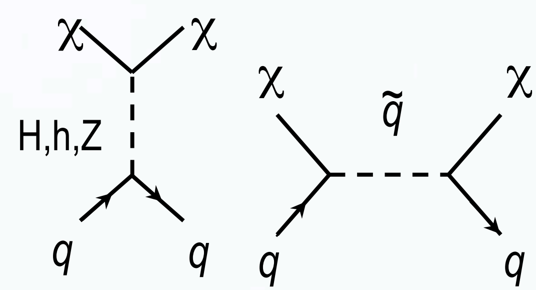


Direct Detection of WIMPs

1. Particle Physics: Interaction cross section with target material

WIMPs elastically scatter off nuclei in targets, producing nuclear recoils.

$$R \propto N \frac{\sigma_{\chi N}}{m_\chi} \rho_\chi \int_{v_{min}}^{v_{esc}} \frac{f(v)dv}{v}$$



(a) Spin-independent interaction μA^2
(large λ_{dB} ➔ coherent interaction)

(b) Spin-dependent needs target with net spin

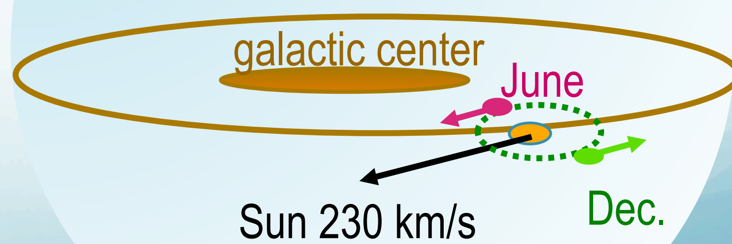
2. Astrophysics: WIMP distribution in our galaxy

Isothermal, spherical halo and M-B velocity dist:

$$f(v)dv = \frac{4v^2}{v_0^3\sqrt{\pi}} e^{-v^2/v_0^2} d^3v$$

$v_0 \sim 230$ km/s $\quad v_{esc} \sim 550$ km/s

$\rho_\chi = 0.3$ GeV / cm^3



WIMP Spectrum in a Detector

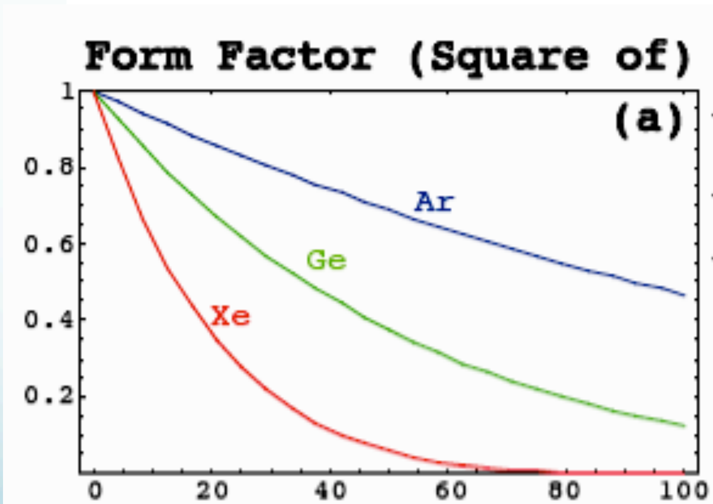
Results in a Featureless Exponential Recoil spectrum

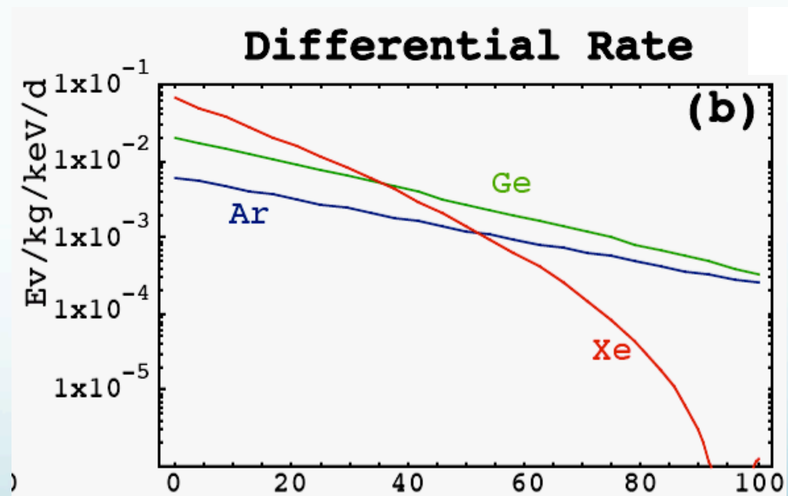
Energies in the tens of keV ➔ Need Very Sensitive Detectors
Rate of < .1 evt/kg/yr ➔ Need Very Low Background

Details and Fall-off depend on Nuclear Physics of Target Material

$$\frac{dR}{dE_R} = \frac{\sigma_0 \rho_0}{2 m_\chi \mu^2} F^2(E_R) \int_{v_{min}}^{v_{max}} \frac{f(v)}{v} dv$$

Ar: A = 40
Ge: A = 73
Xe: A = 131

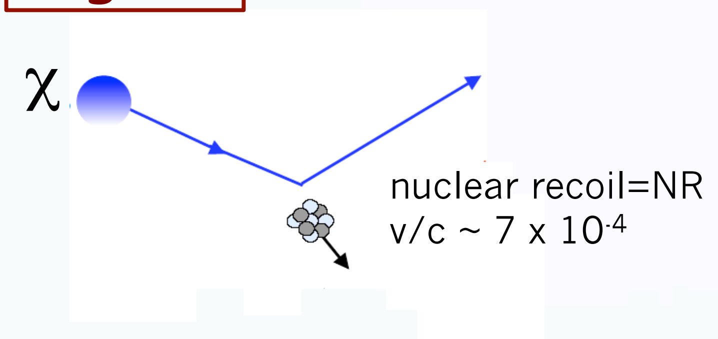




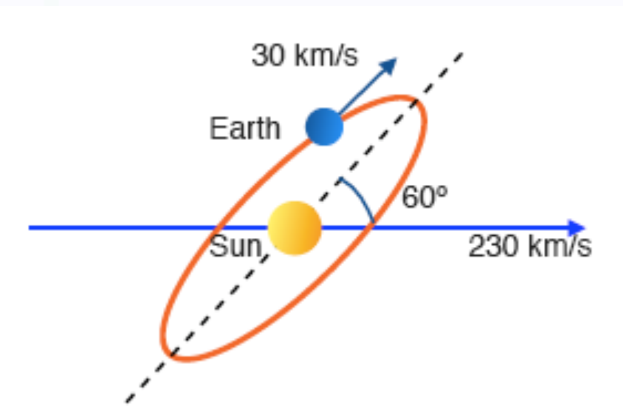
Recoil Energy (keV)

Choose your Technique

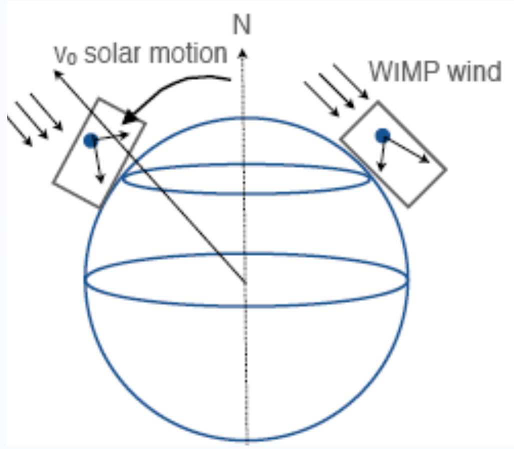
Signal



Count nuclear recoils

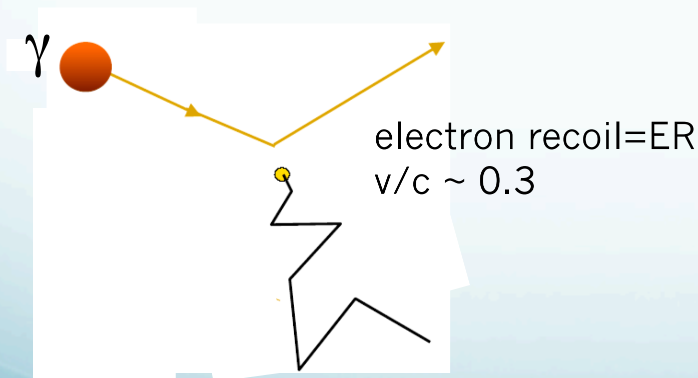


annual flux variation



diurnal directional modulation

Background

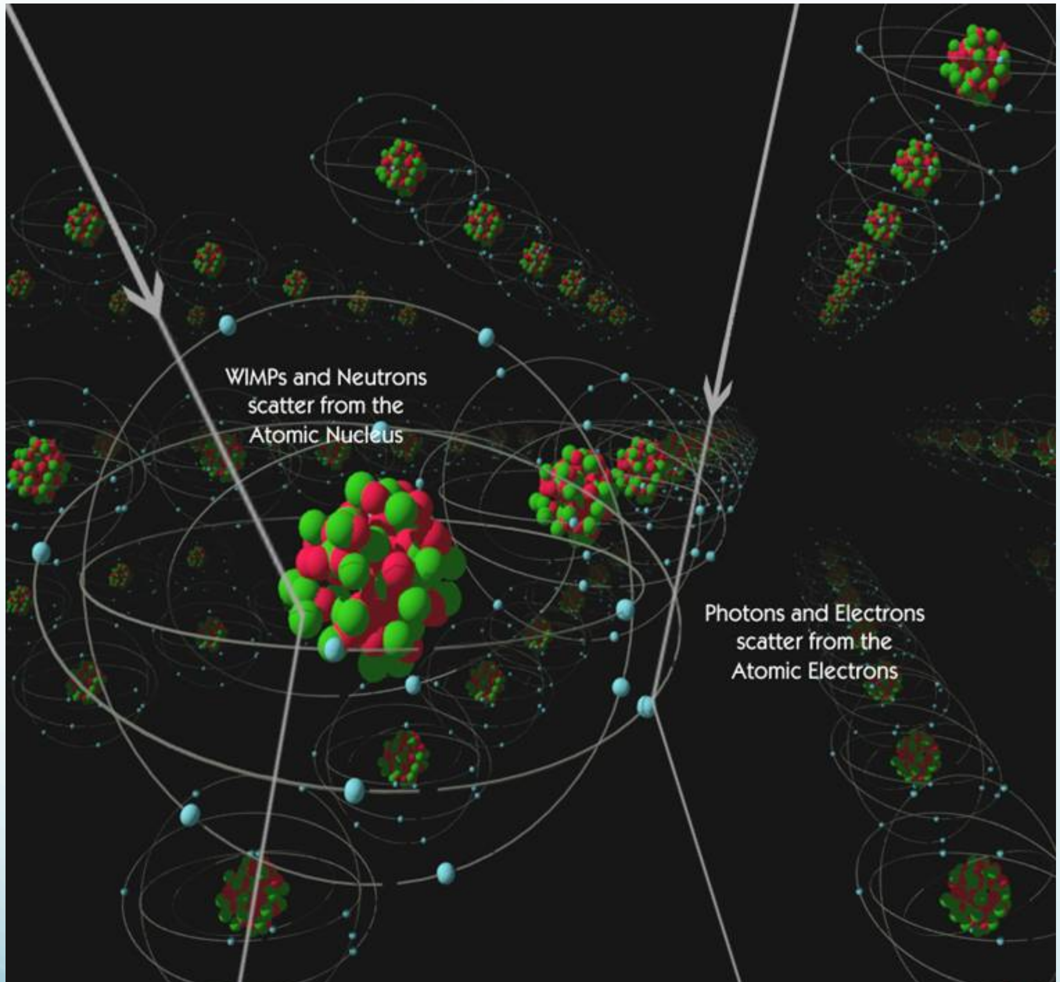


β,γ **discriminate** between ER vs NR
-or- eliminate sensitivity to ER
-or- self-shielding

n multiple scatters
σ varies with target
} **avoid** shielding, go deep

α much higher energy deposit.
problem for threshold devices, trackers

Removing Electromagnetic Backgrounds



M. Attisha

Exploit media with a different response to

NR: Nuclear Recoils
and
ER: Electron Recoils

to distinguish between WIMPs and background

Two-channel strategy:
One signal with NR/ER < 1
Another to normalize energy scale

Counting Nuclear Recoils: Types of Signals

heat, vibration

Germanium, Silicon

$CaWO_4$, sapphire

light

NaI, CsI, $CaWO_4$

Liquid Ar, Xe

high pressure Xe

charge

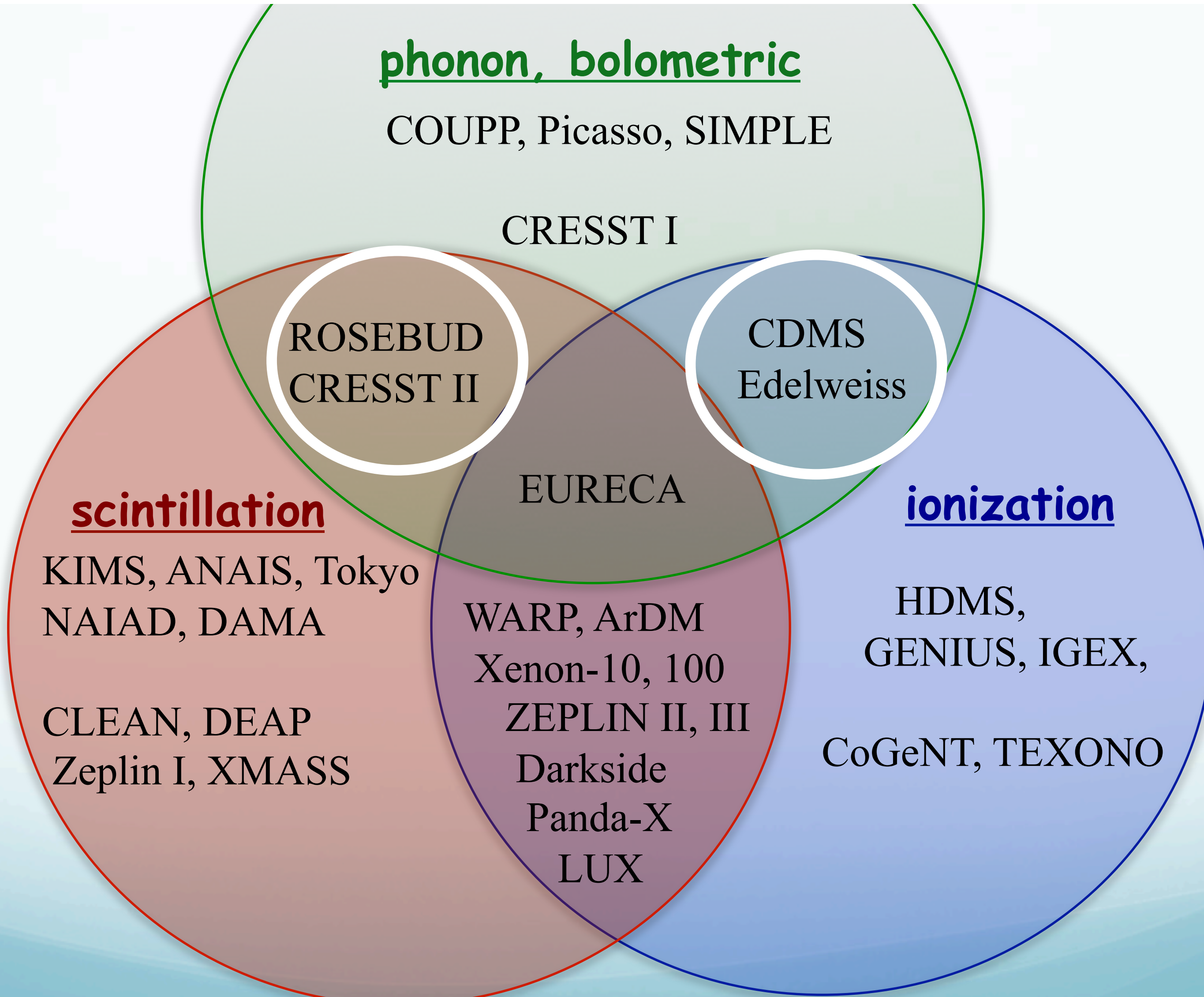
Germanium, Silicon

Liquid Ne, Ar, Xe

Gas: Ne, Xe, Ar,
C_2H_6, CF_4 etc…

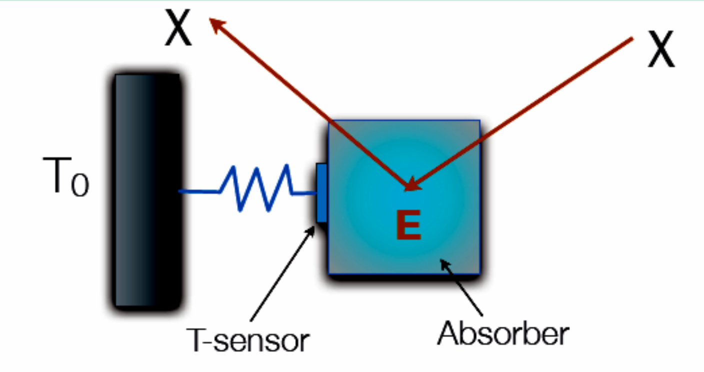
Counting Nuclear Recoils: Experiments

two signals are better than one



Cryogenic Techniques at mK Temperatures

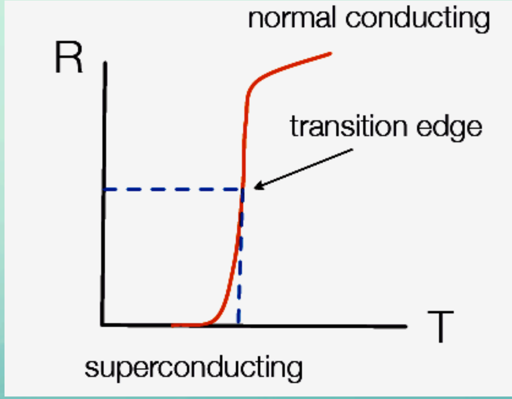
Need sensitivity (big ΔT) for small ΔE, so run at T << T_c



$$C(T) = \frac{\Delta E}{\Delta T} \propto T^3$$

Phonon Signal: **CRESST, CDMS**
Superconducting Transition Edge Sensors (TES) + SQUID readout

Bolometric: **ROSEBUD, EDELWEISS**
Neutron transmutation-doped Ge (NTD-Ge) sensor +FET



Cryogenic Techniques at mK: *the other channel*

+ Ionization | *+ Scintillation*

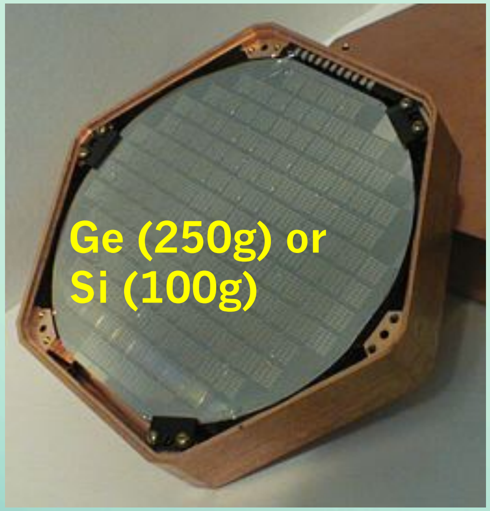
CDMS II (Soudan) | **EDELWEISS** (Modane) | **CRESST II** (Gran Sasso)

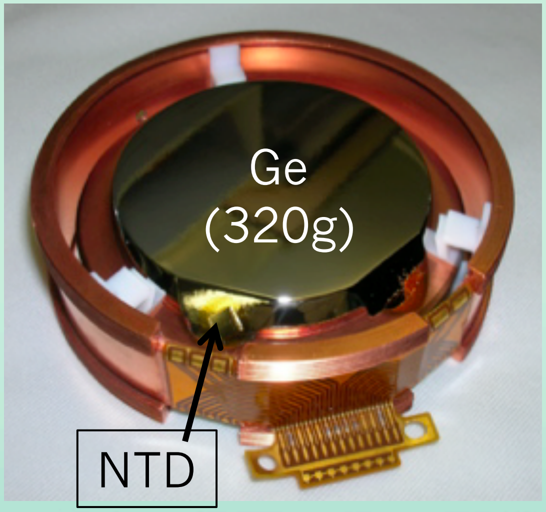
Apply voltage across crystal

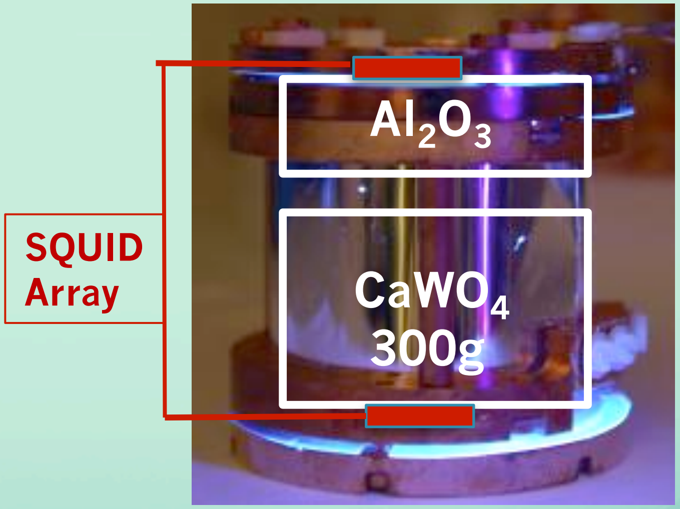
Read out drifted charge from FETs

light from $CaWO_4$ via sapphire-silicon sensor

W-TES on Al_2O_3+ SQUIDs







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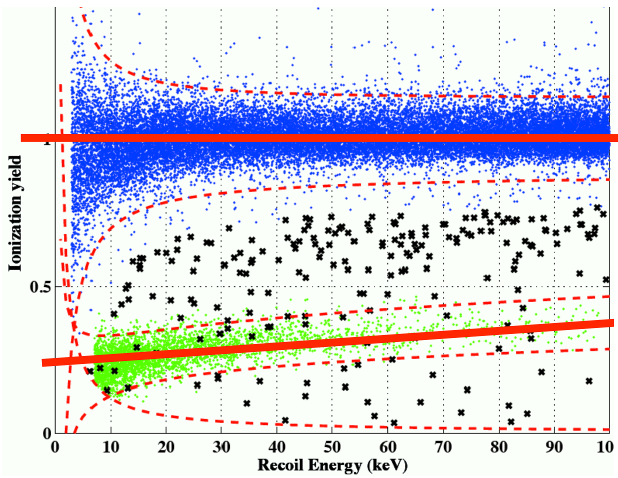
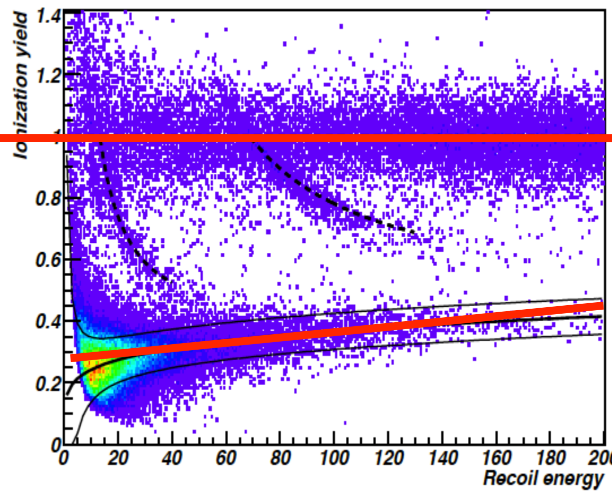
CDMS II (Soudan) | **EDELWEISS** (Modane) | **CRESST II** (Gran Sasso)

Data from radioactive source calibration

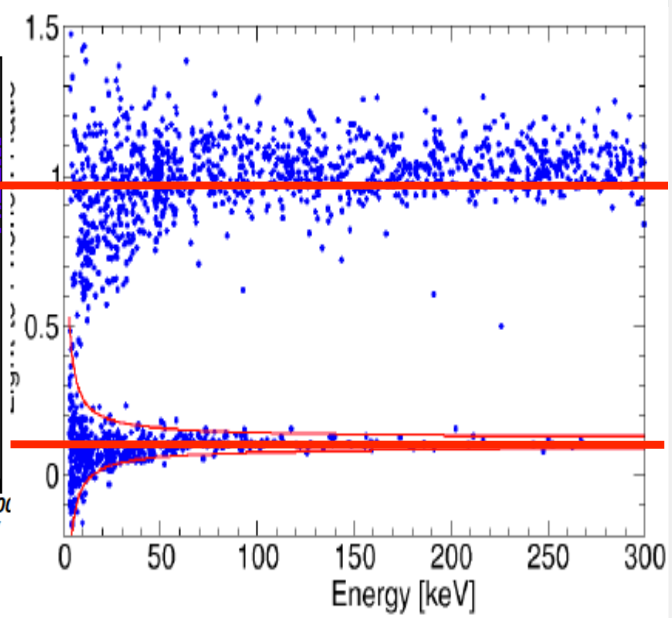
Charge to Phonon ratio



Charge to Heat ratio



Light to Phonon ratio



NR Quenched by factor ~ 3

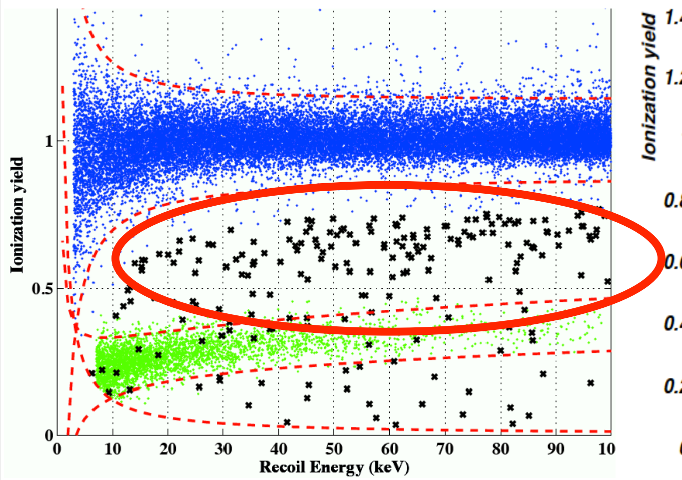
Q(O) ~ 9 ER/NR from CaO
Q(W) ~ 40 ➔ insensitive to n
but big A^2 effect for WIMPs

Cryogenic Techniques at mK: *Surface Events*

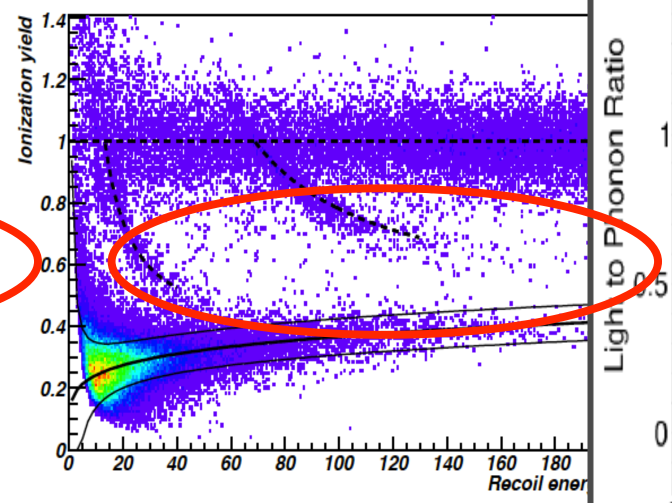
CDMS II (Soudan) | **EDELWEISS** (Modane) | **CRESST II** (Gran Sasso)

Data from radioactive source calibration

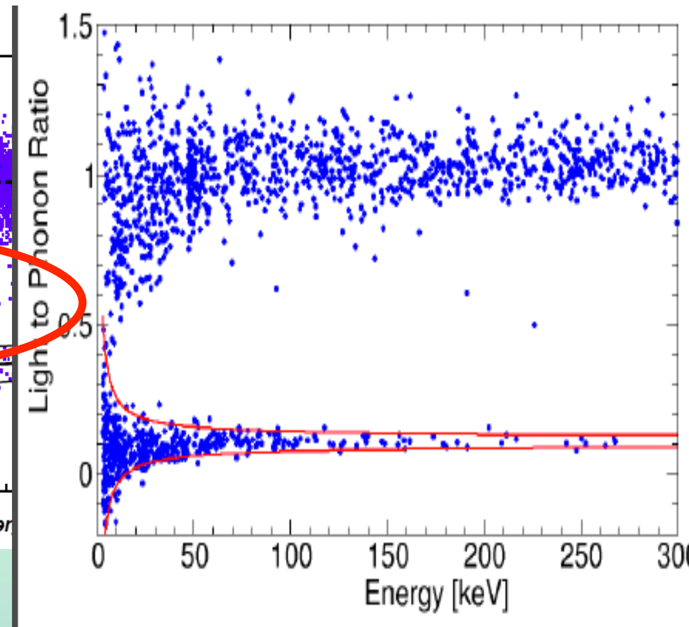
Ionization to Phonon ratio



Ionization to Heat ratio



Light to Phonon ratio

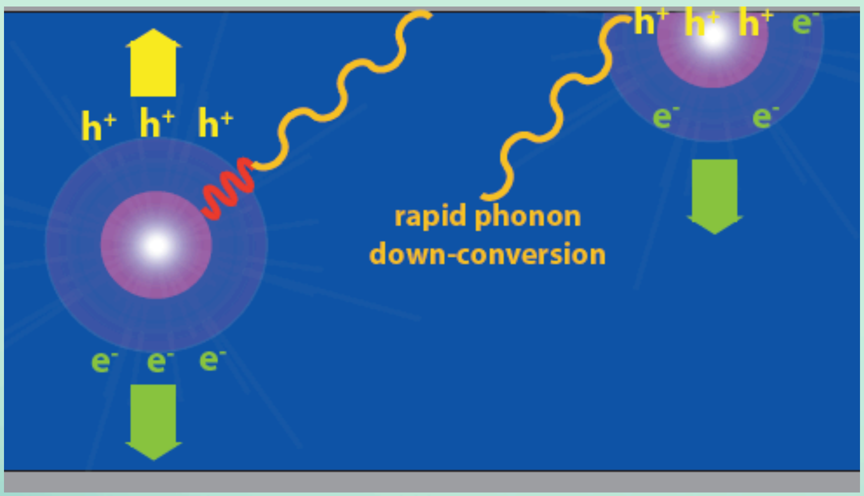


Incomplete charge collection for low energy β
Ionization ratio droops into NR band

Rejecting Surface Events: Timing

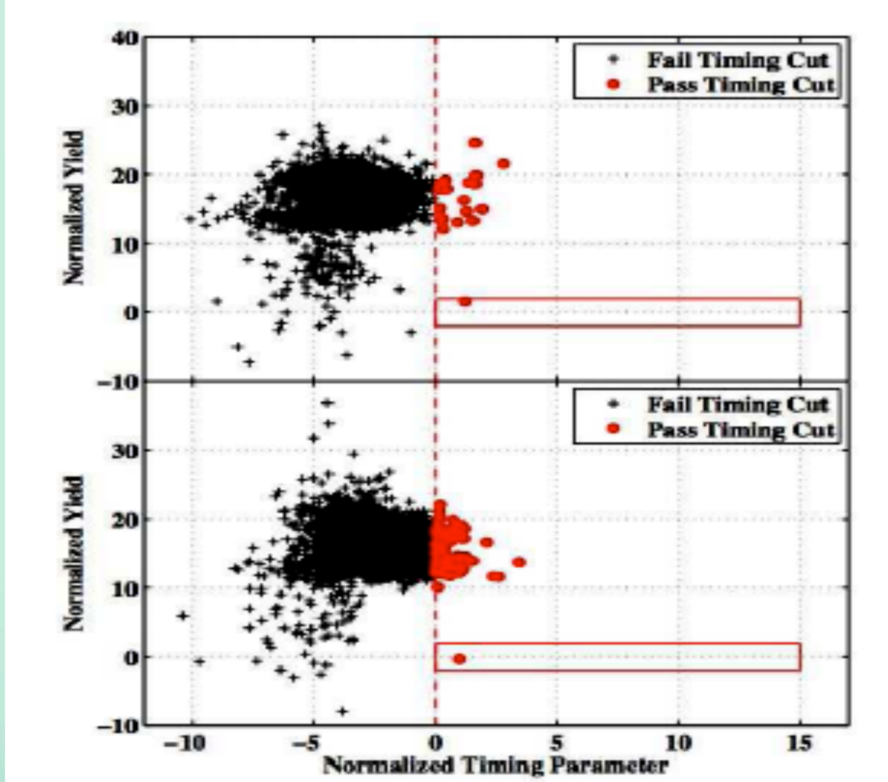
CDMS II

phonon pulse shape gives another handle



Phonons created near surface travel faster through crystal (ballistic)

Data from WIMP Search

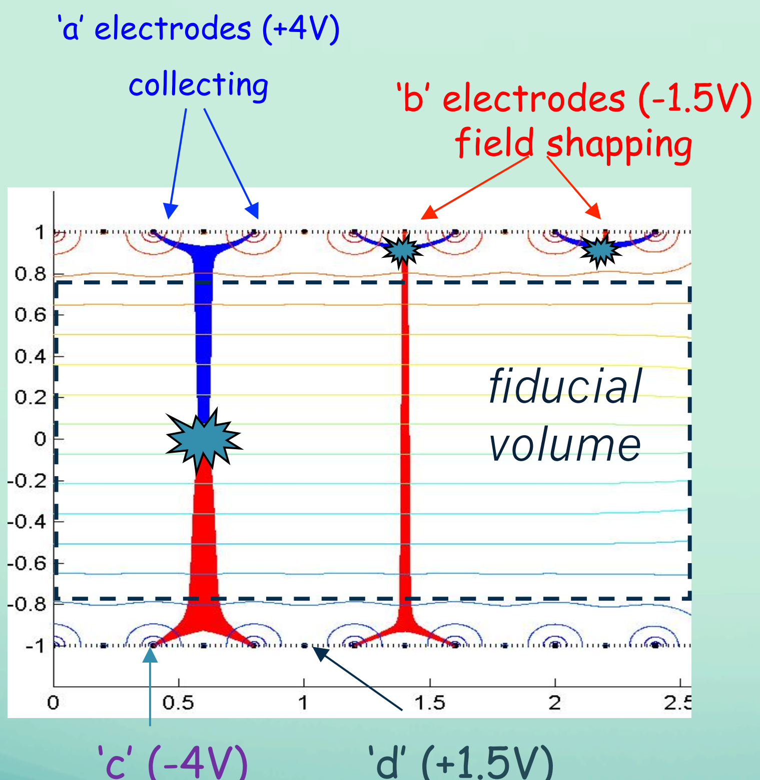


Timing Parameter
linear combination of risetime and delay

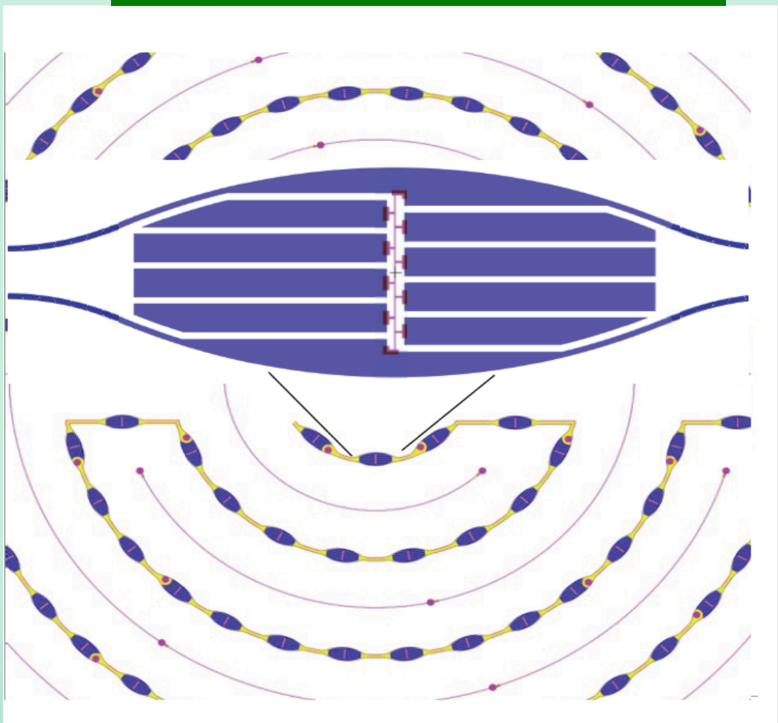
Rejecting Surface Events: Interleaved Electrodes

Charge near surface is collected by electrodes on only one side

EDELWEISS II



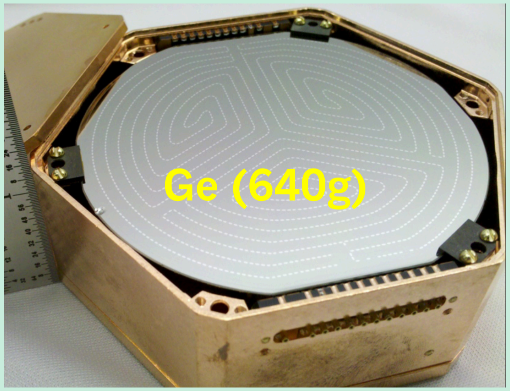
SuperCDMS Soudan



Cryogenic Techniques at mK: *Improved Detectors*

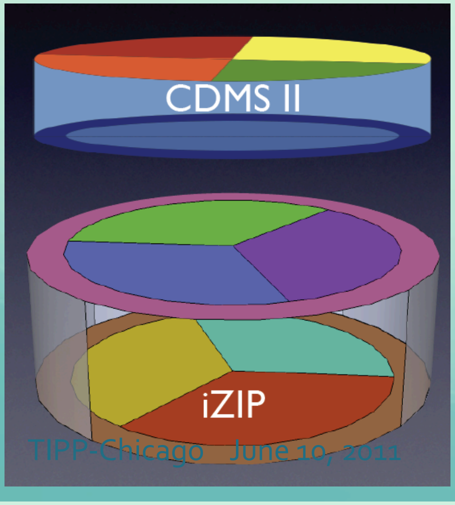
SuperCDMS (Soudan) | **EDELWEISS II (Modane)** | **CRESST II (Gran Sasso)**

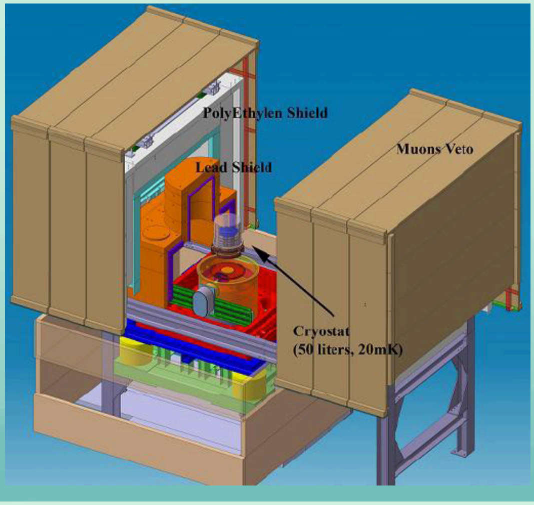
Improved Surface Event rejections via Larger Detectors
New interleaved electrodes → surface event rejection



phonon and charge on both sides

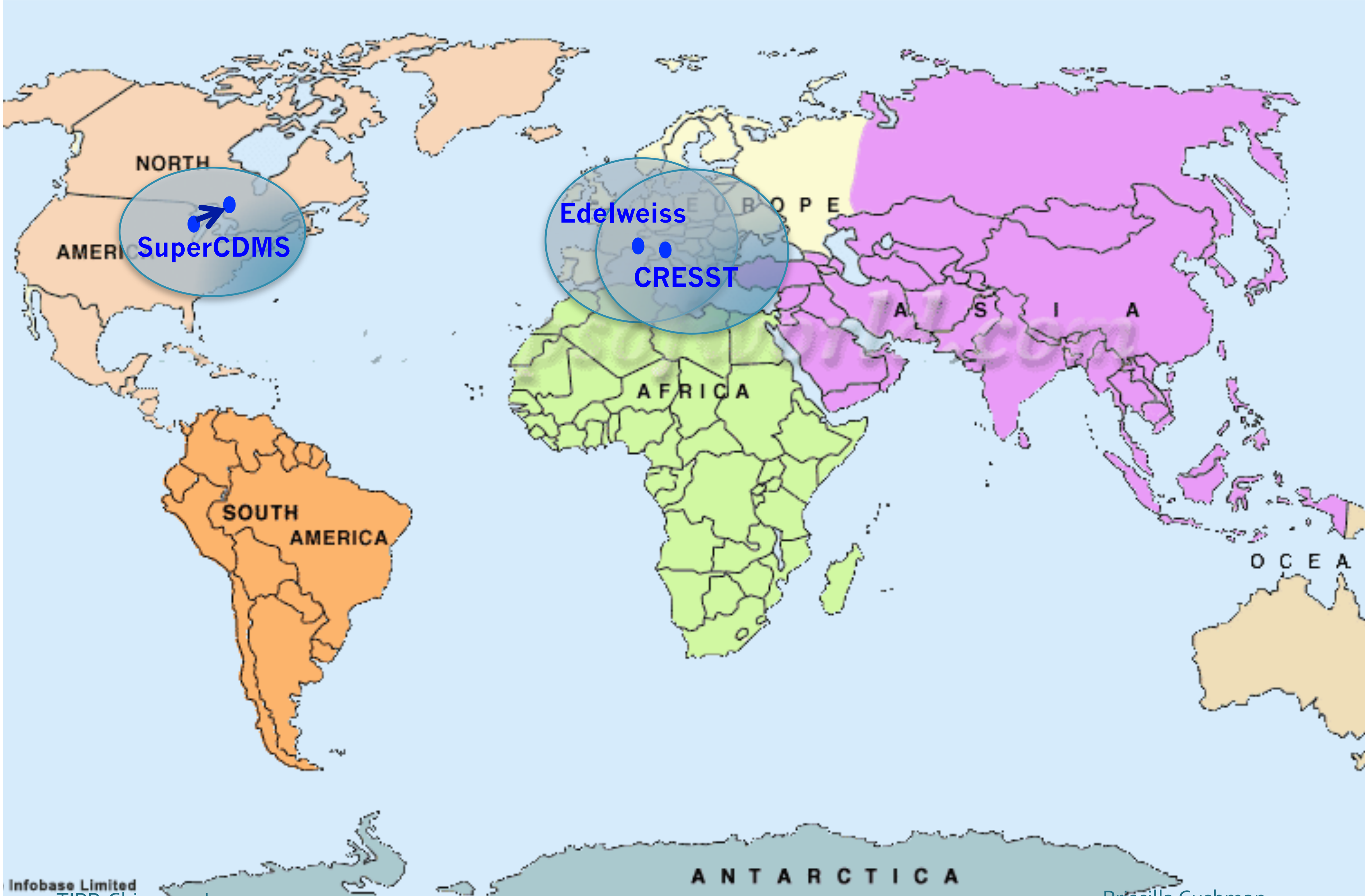
2 NTD, 6 electrodes
new cryostat – up to 40 kg





More mass & multiple targets
Composite detector design
(simplified TES)
Improve clamps to reduce bkgd
mechanical (dark evts)
scint veto (^{210}Pb α,NR)

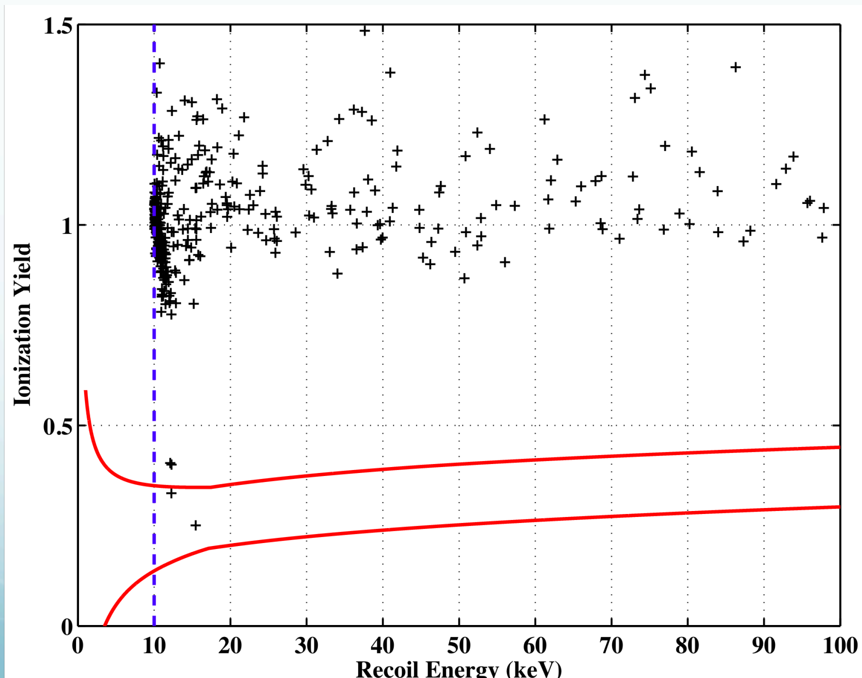
Underground Labs with Cryogenic Solid State



Snapshot: All three have unexplained backgrounds … WIMP hint?

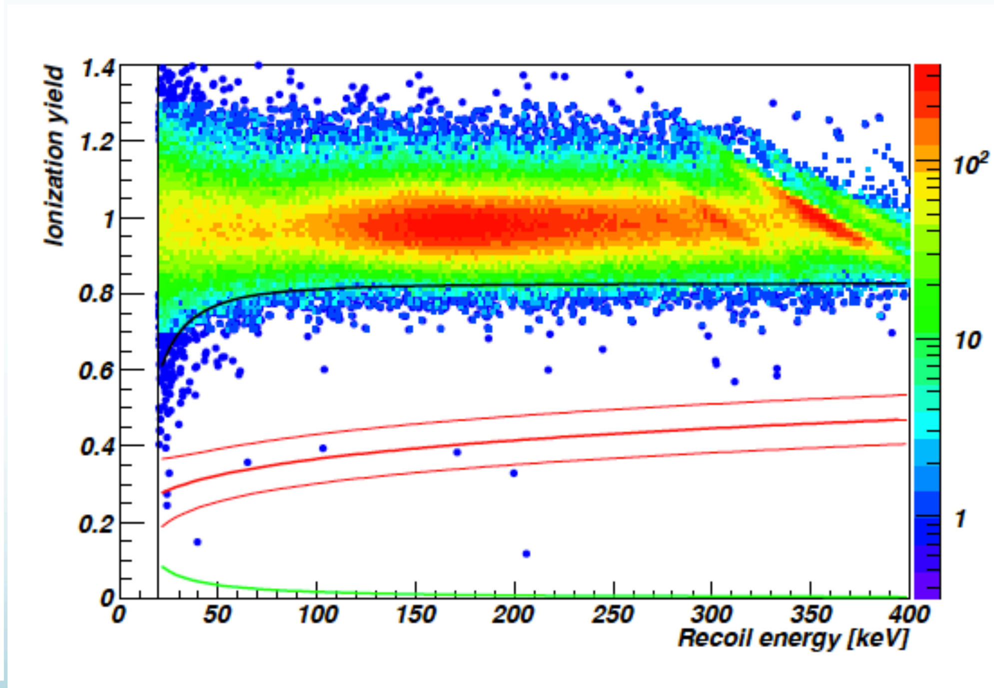
CDMS II

Blind analysis gave 2 evts
bkgd of 0.8 ± 0.1(stat) ± 0.2(sys)
23% probability to observe ≥ 2 evts



EDELWEISS II (interleaved)

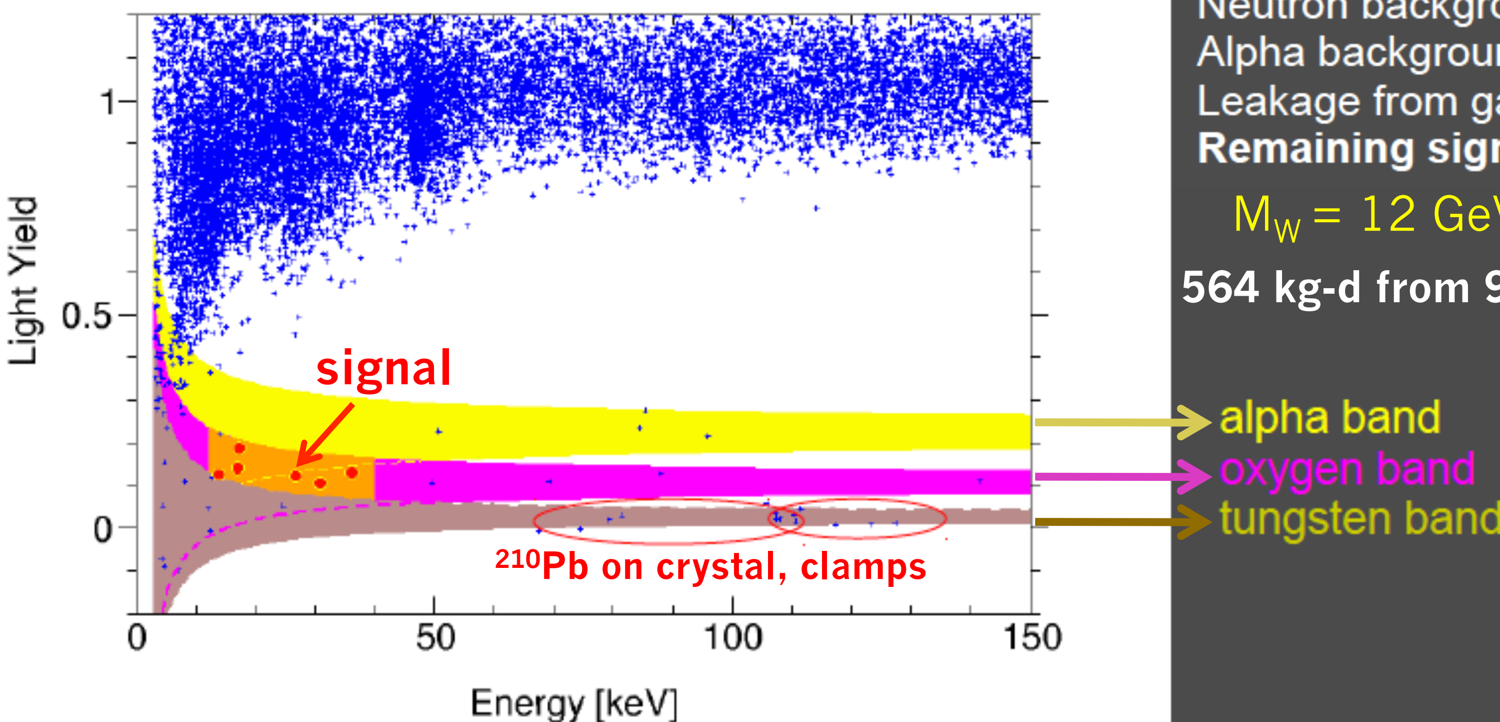
Blind-ish analysis gave 5 evts
bkgd studies still proceeding
Expected < 3 evts



Snapshot: All three have unexplained backgrounds … WIMP hint?

CRESST II oxygen events

one crystal out of 9

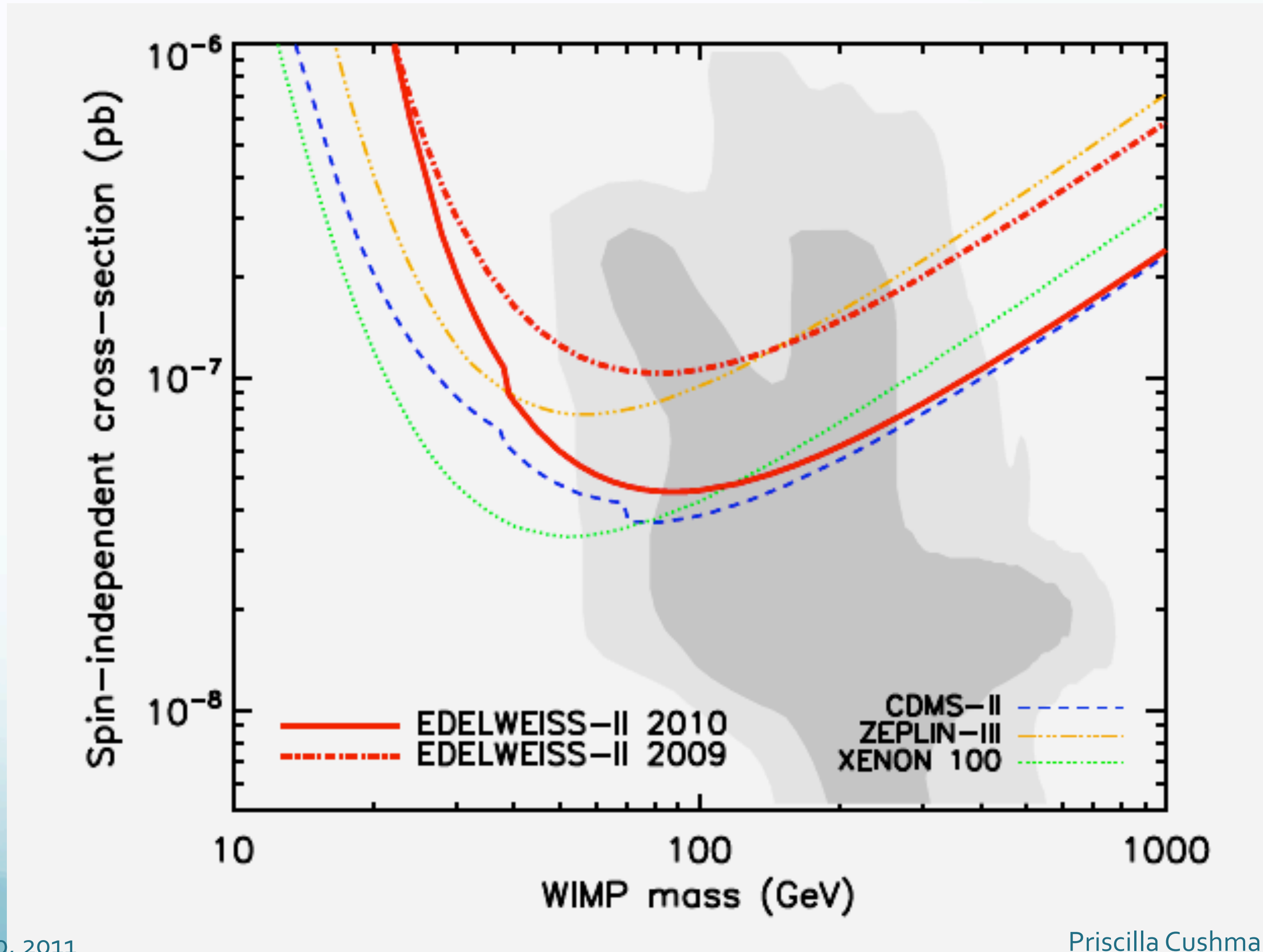


Counts in signal region	**32**
Neutron background	0.8
Alpha background:	6.8
Leakage from gamma band:	1.2
Remaining signal:	**23.2**

M_W = 12 GeV/c^2 @ 5.4 σ

564 kg-d from 9 $CaWO_4$ crystals

Snapshot: All three have unexplained backgrounds … Set Limits

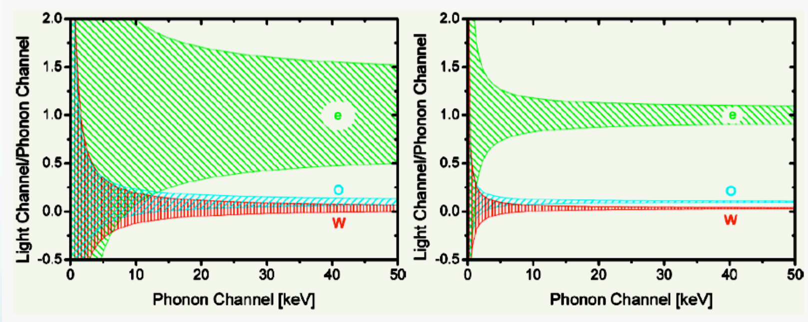


Challenges for Cryogenic Phonon

SuperCDMS & Edelweiss, bkgd challenge largely met!

Surface contamination (betas) ➔ Fiducial cut using
Phonon timing
Interleaved electrodes
should be good enough for ton scale experiment

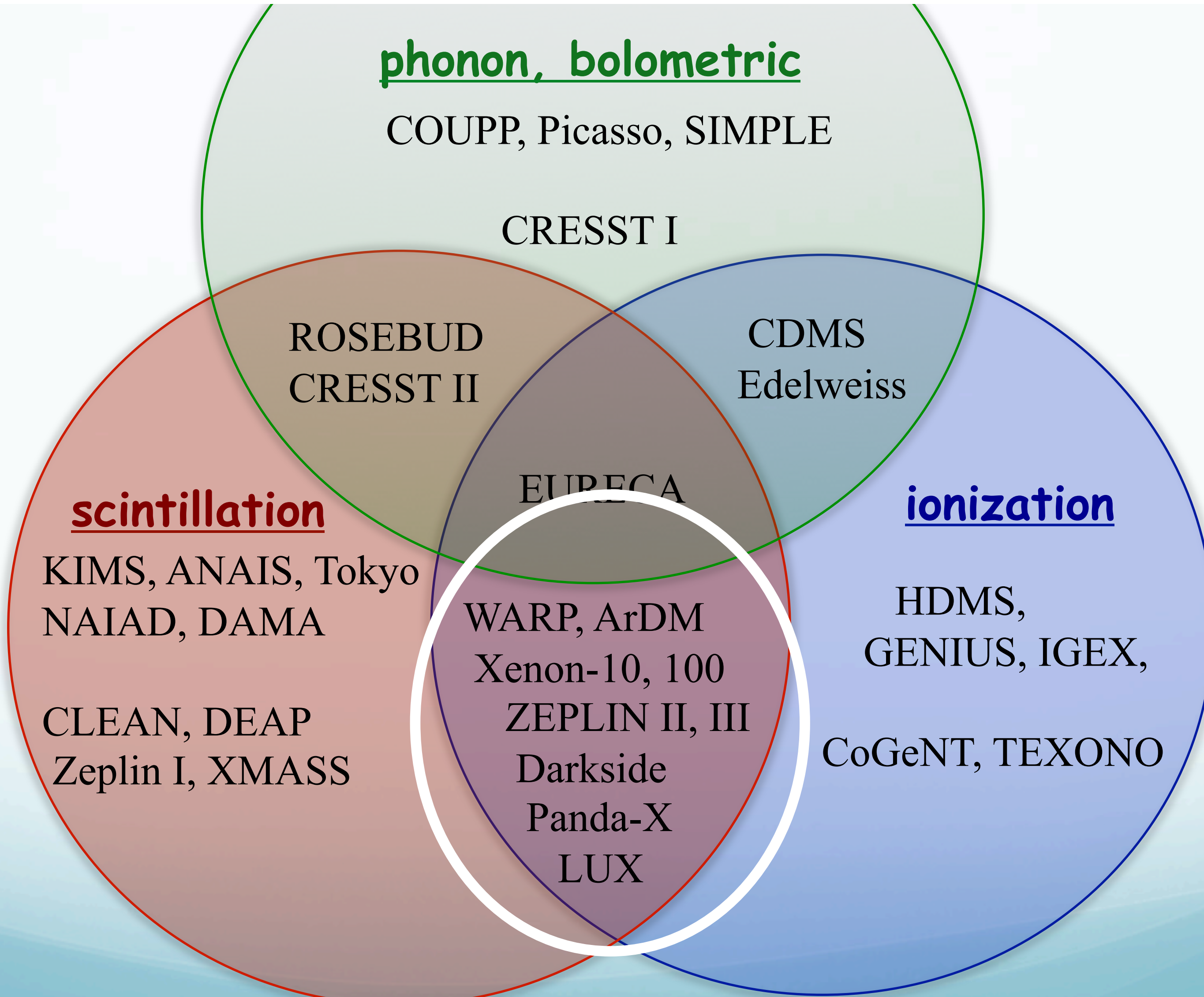
CRESST II More exposure (more neutron multiples to benchmark)
Reduce alphas (contamination and clamps)
Improve light collection and lower threshold



Main issues are
- Complexity and Scaling up
- Material cost (e.g. Ge $20/g)
- Cryogenic demands

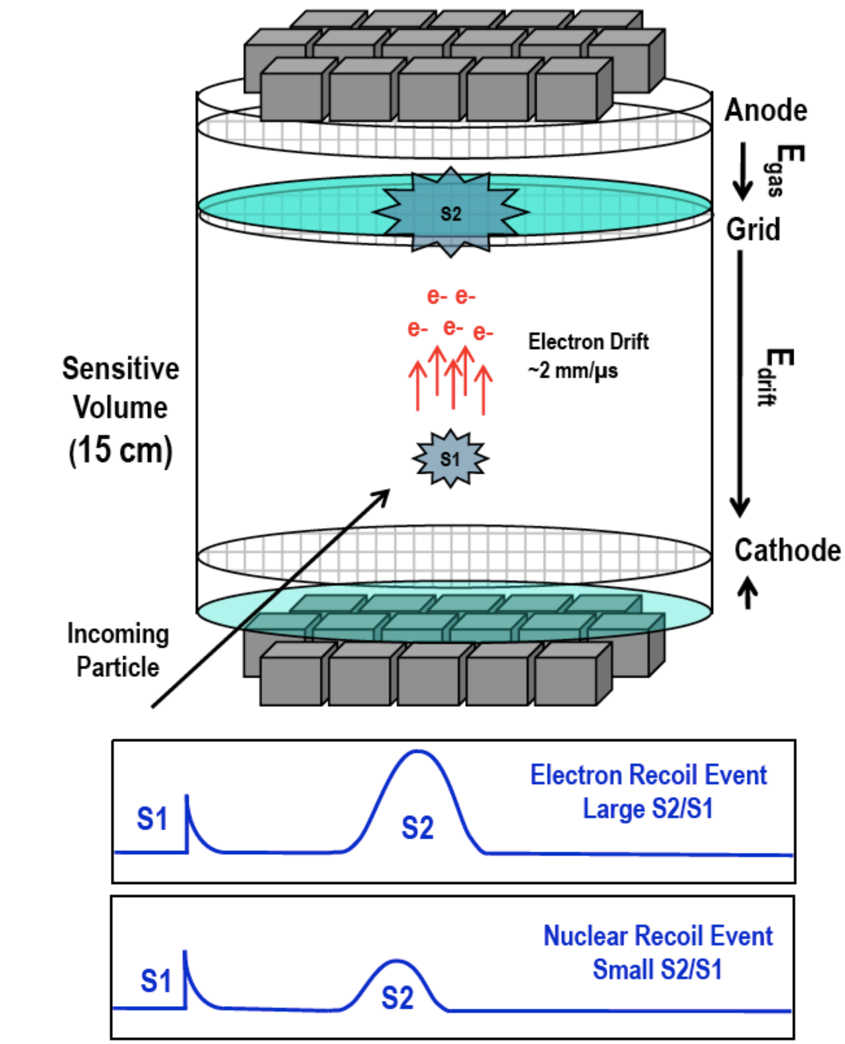
Counting Nuclear Recoils: Experiments

two signals are better than one

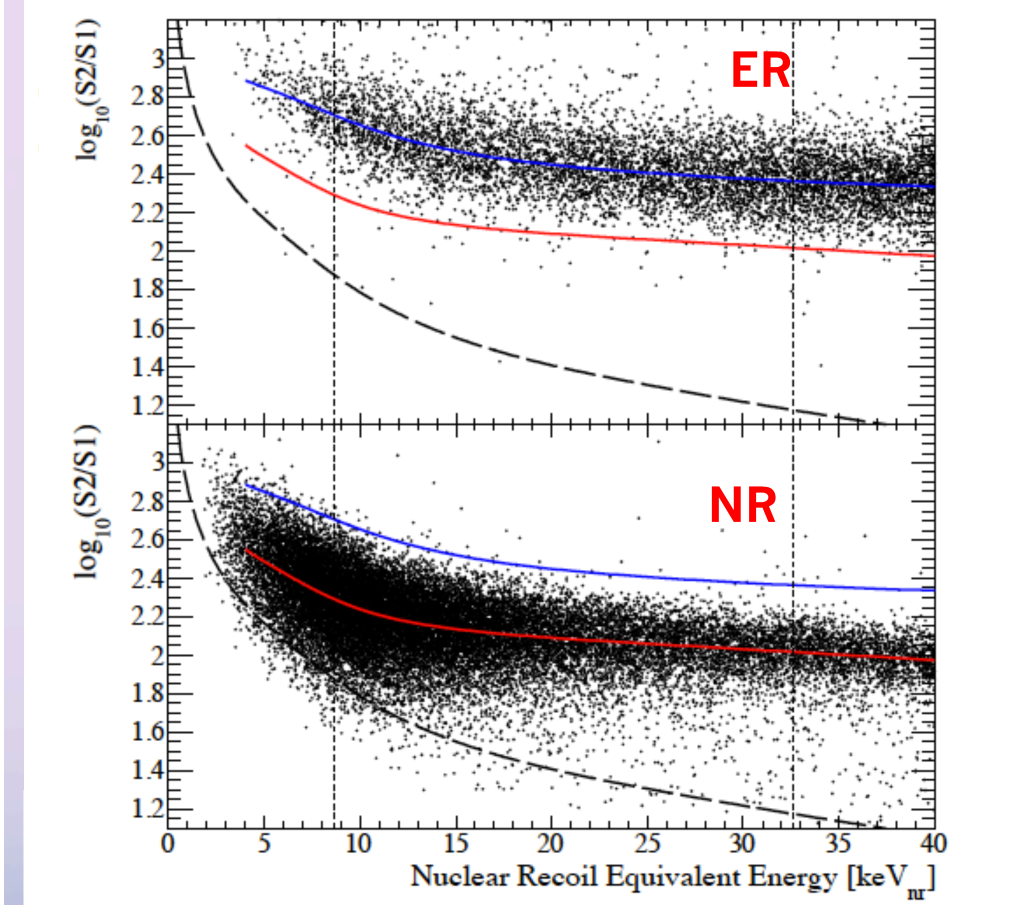


Ionization + Scintillation: *Two-Phase Noble Liquids*

Time Projection Chamber technology



^{60}Co and ^{241}AmBe calibration data



XENON100: Aprile et al. arXiv:1005.0380v3

Ionization + Scintillation: *Two-Phase Noble Liquids*

Choose your working fluid

Argon	Xenon
A = 40	A = 131, form factor reduction at higher E_r
λ = 128 nm (λ-shifter)	λ = 125 nm (UV PMT)
$2/kg	$800/kg
100% even-even nuclei	50% odd-n nuclei
^{39}Ar (1Bq/kg in Nat Ar) new sources from wells	^{85}Kr (removed via filter or distillation)

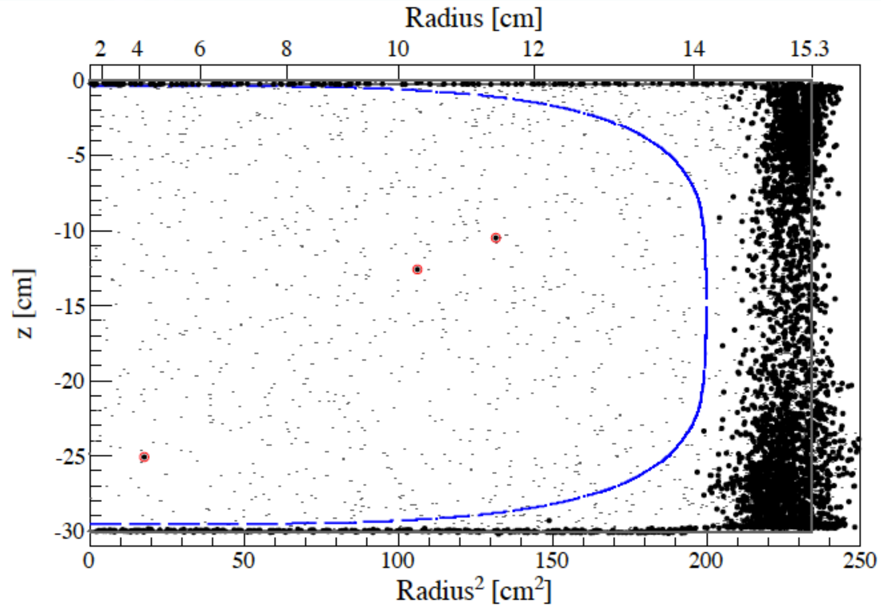
Ionization + Scintillation: *Two-Phase Noble Liquids*

Lots of experiments !

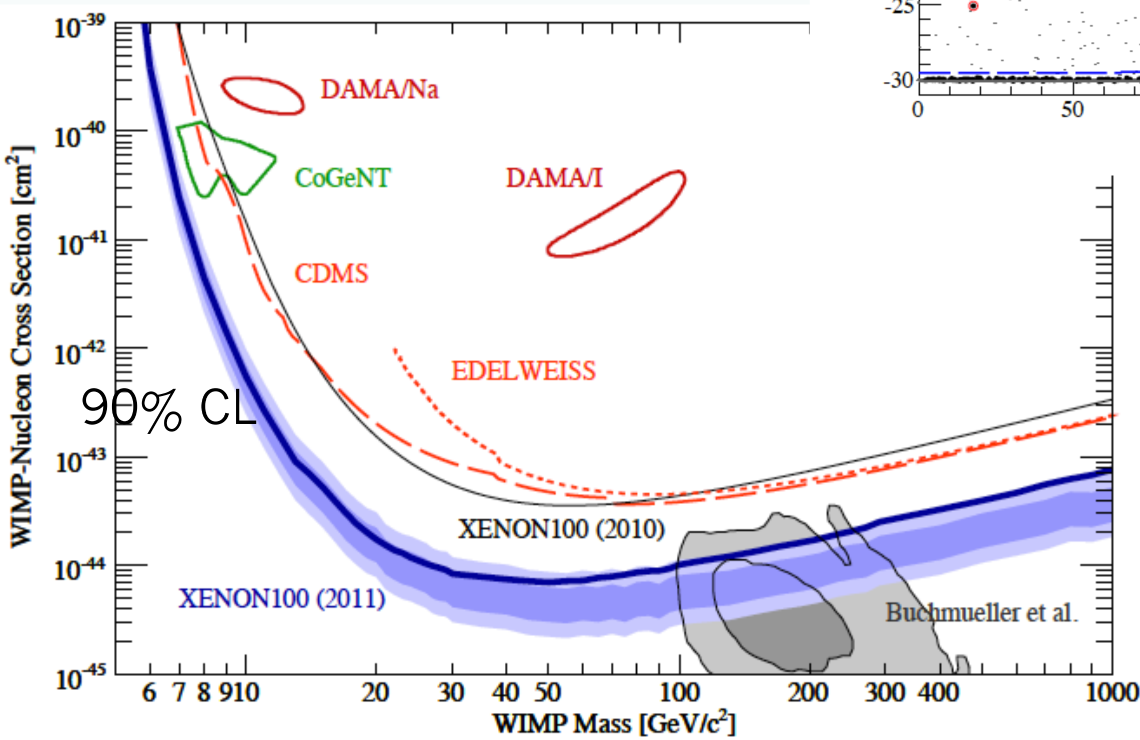
Liq Xenon	Location	Tot (Fid) kg	
Xenon10	LNGS	15 (5.4)	finished
Xenon100	LNGS	170 (65)	running
Zeplin II	Boulby	31 (7.2)	finished
Zeplin III	Boulby	12 (6.5)	running
LUX	Sanford	300 (100)	testing
Panda-X	JinPing	120 (25)	testing

Liq. Argon	Location	Tot (Fid) kg	
WArP	LNGS	3.2	finished
WArP	LNGS	8T (140)	running
ArDM	CERN/Canfranc	850 kg	testing
Darkside	LNGS	50 kg prototype	testing

Snapshot: XENON100 sets best limit



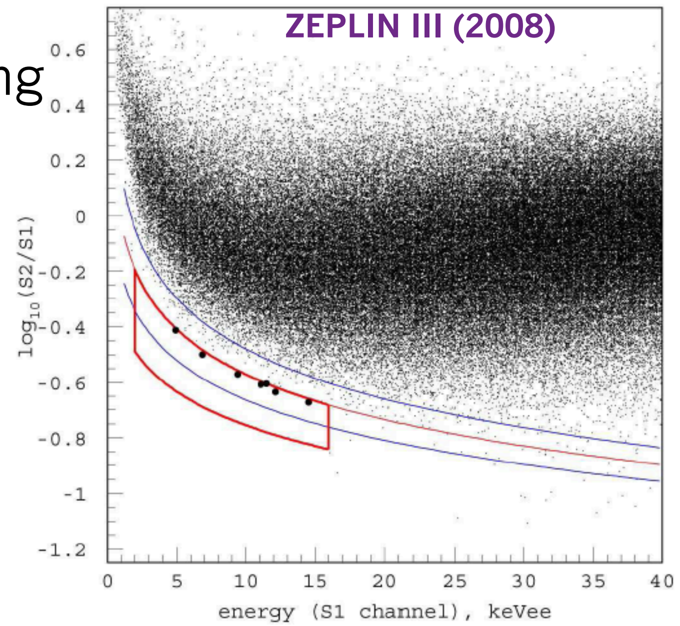
arXiv:1104.2549



90% CL

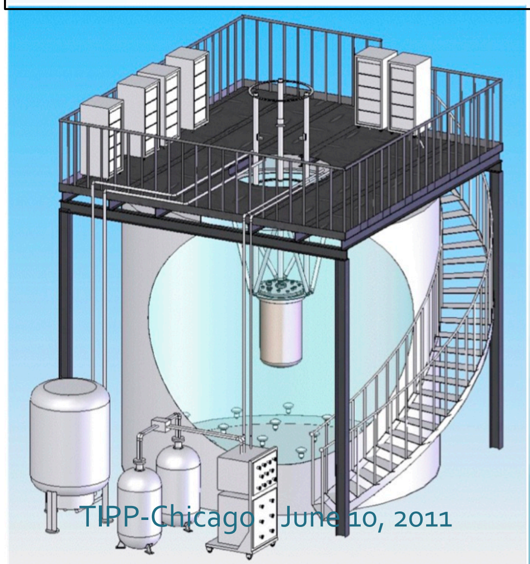
Results from the others expected in the next couple years

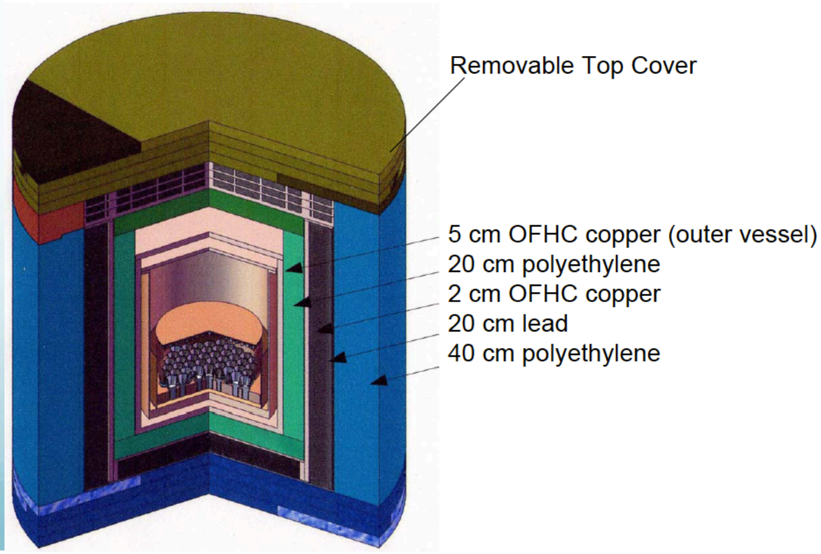
WArP-140 is currently running



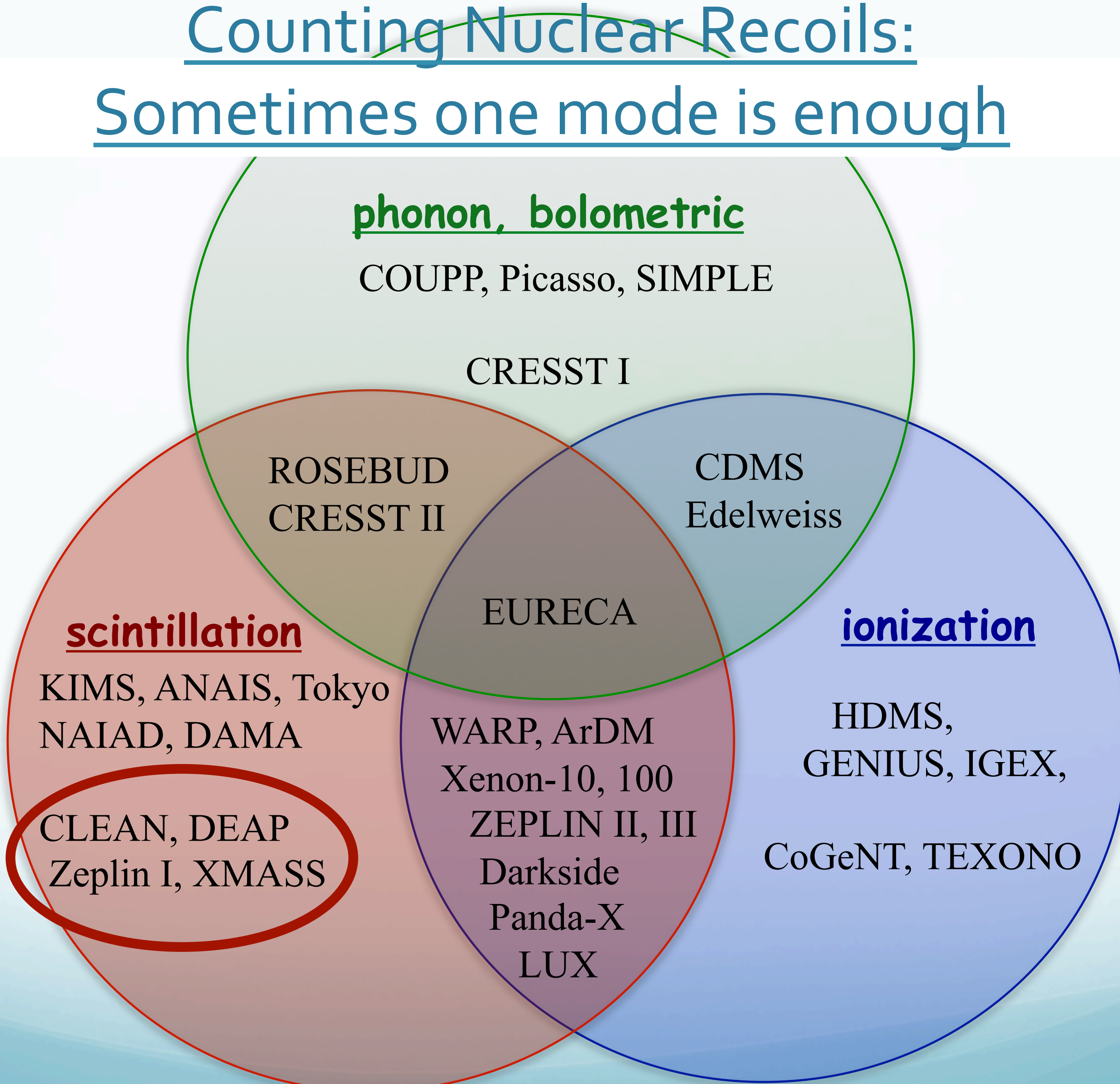
ZEPLIN III final run will end this summer
- ~1500 kg-d with neutron veto
- new PMTs (18x bkgd reduction)

LUX surface testing now Underground Spring 2012 Large water tank	Panda-X complete by Fall 2011 Deep! no active shield





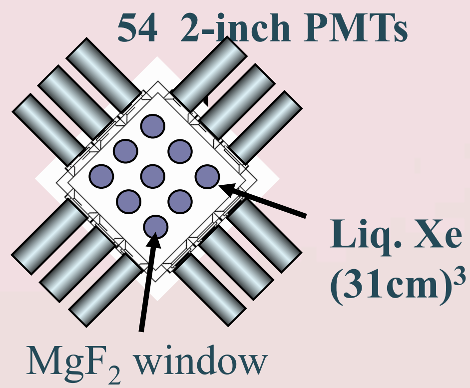
Counting Nuclear Recoils: Sometimes one mode is enough

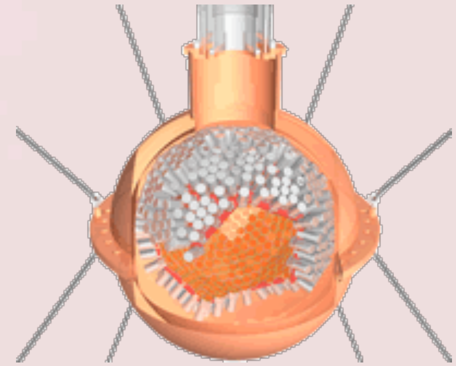


Scintillation: *Single Phase Noble Liquids*

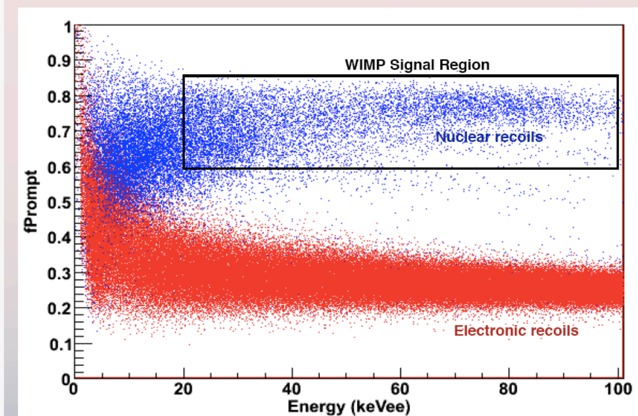
Liquid Xenon: Large self-shielded mass, remove all contaminants, fiducial cuts

XMASS (Kamioka)
100 kg prototype ➔ 800 kg





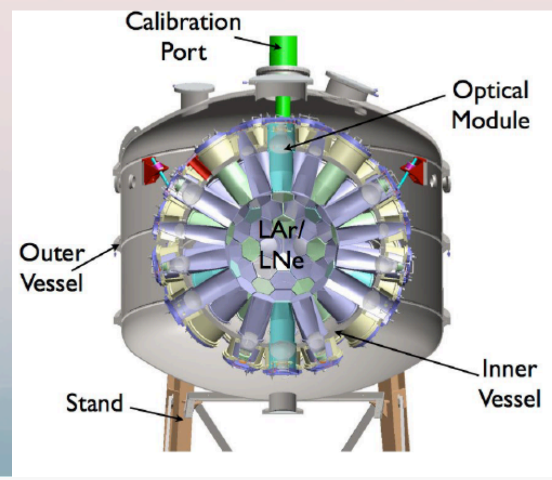
Liquid Argon: Exploit pulse-shape discrimination against ER



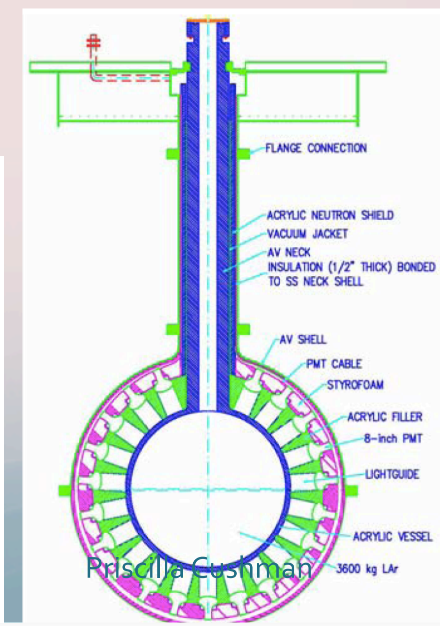
ratio of fast (6ns) to slow (1.6us) scint. components is larger for NR

DEAP/CLEAN (SNOLab)

miniCLEAN



DEAP-3600



Snapshot: Single Phase Noble Liquids

XMASS has extraordinary purity and lowrad PMTs

100 kg is running now, 800 kg expected in 2012

DEAP/CLEAN

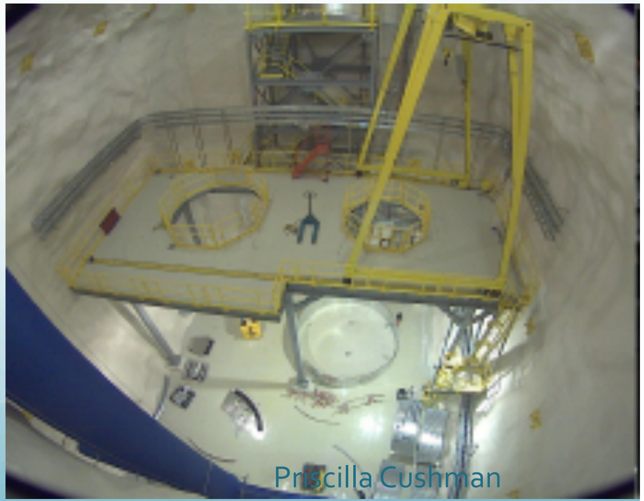
R&D **microCLEAN** (4 kg) LAr/LNe scintillation, PSD, NR quenching
DEAP-1 (7 kg) PSD rejection of 4.7×10^{-8} for 25-86 keV_{ee}

WIMP search starts 2012

MiniCLEAN (500 kg) LAr/LNe to ~ 10^{-45} cm^2
Max light collection/sensitivity (> 6 pe/keV)

DEAP-3600 (3600 kg) LAr/DAr to ~ 10^{-46} cm^2

eventually
CLEAN 10-100 Tons ~ 2×10^{-47} cm^2



Challenges for Noble Liquids

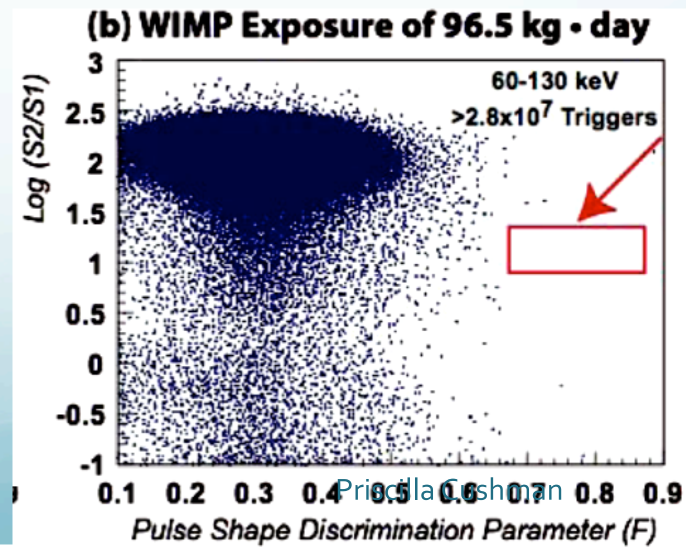
Argon: ^{39}Ar (1 Bq/kg) in atmospheric argon
Depleted argon underground sources (x20)
Good PSD against β-decay

Xenon: ^{85}Kr cryo distillation to < 50 ppt (Xenon100 goal)
XMASS at 3 ppt ^{85}Kr (mass spec), U/Th 10^{-13} g/g

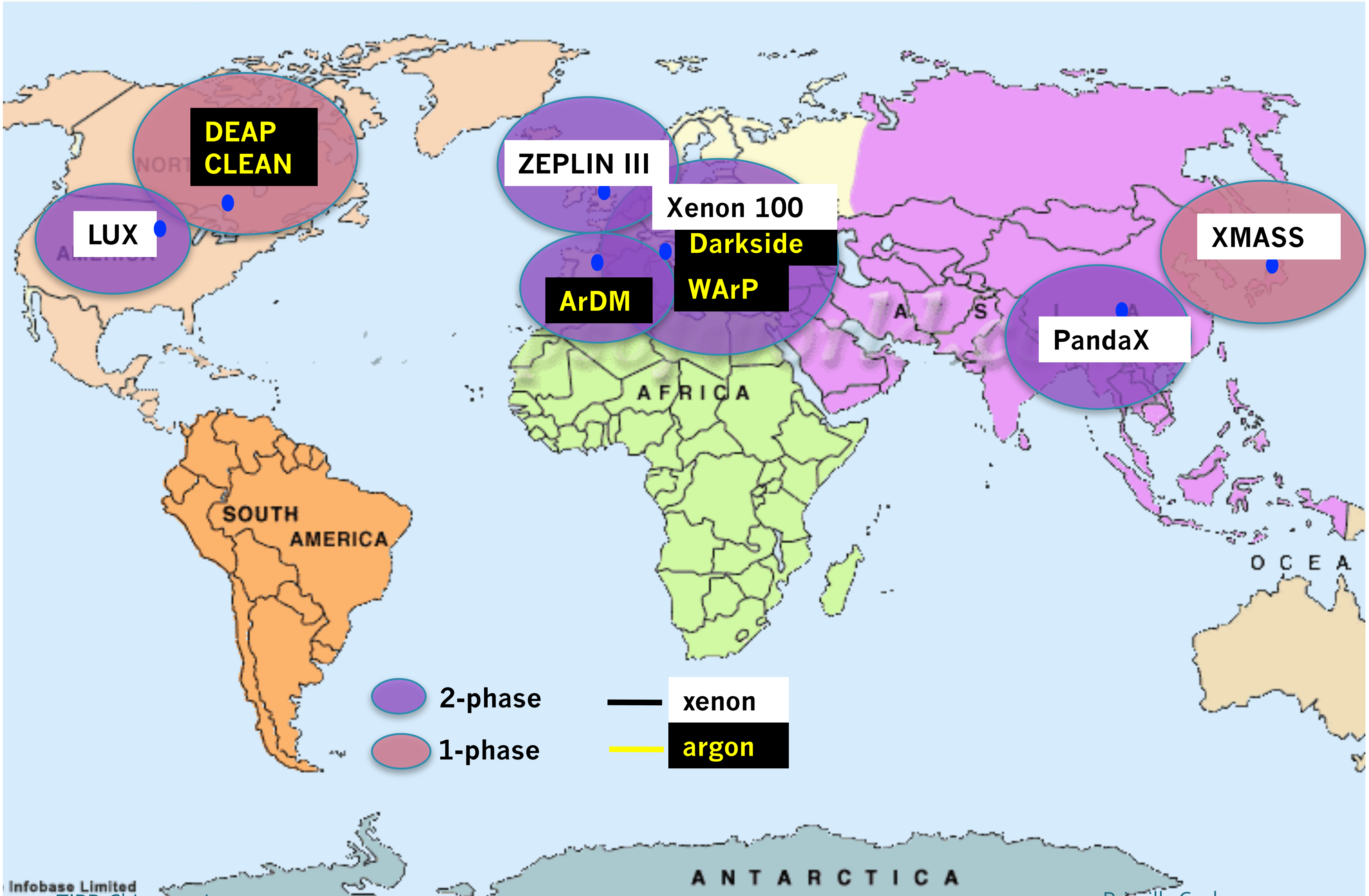
Backgrounds
Gammas reduced by self-shielding (less reliance on ER:NR)
PMT neutrons: New lowrad H8778, APDPMTs (e.g. QUPIDs)
Wire readout (LEMS in ArDM)
Surfaces: Fiducial cuts
Single phase: Max light collection in 4π
Dual phase: drift time discrimination

Scaling up
Cryogenics less demanding than bolometers
Single phase much easier than dual

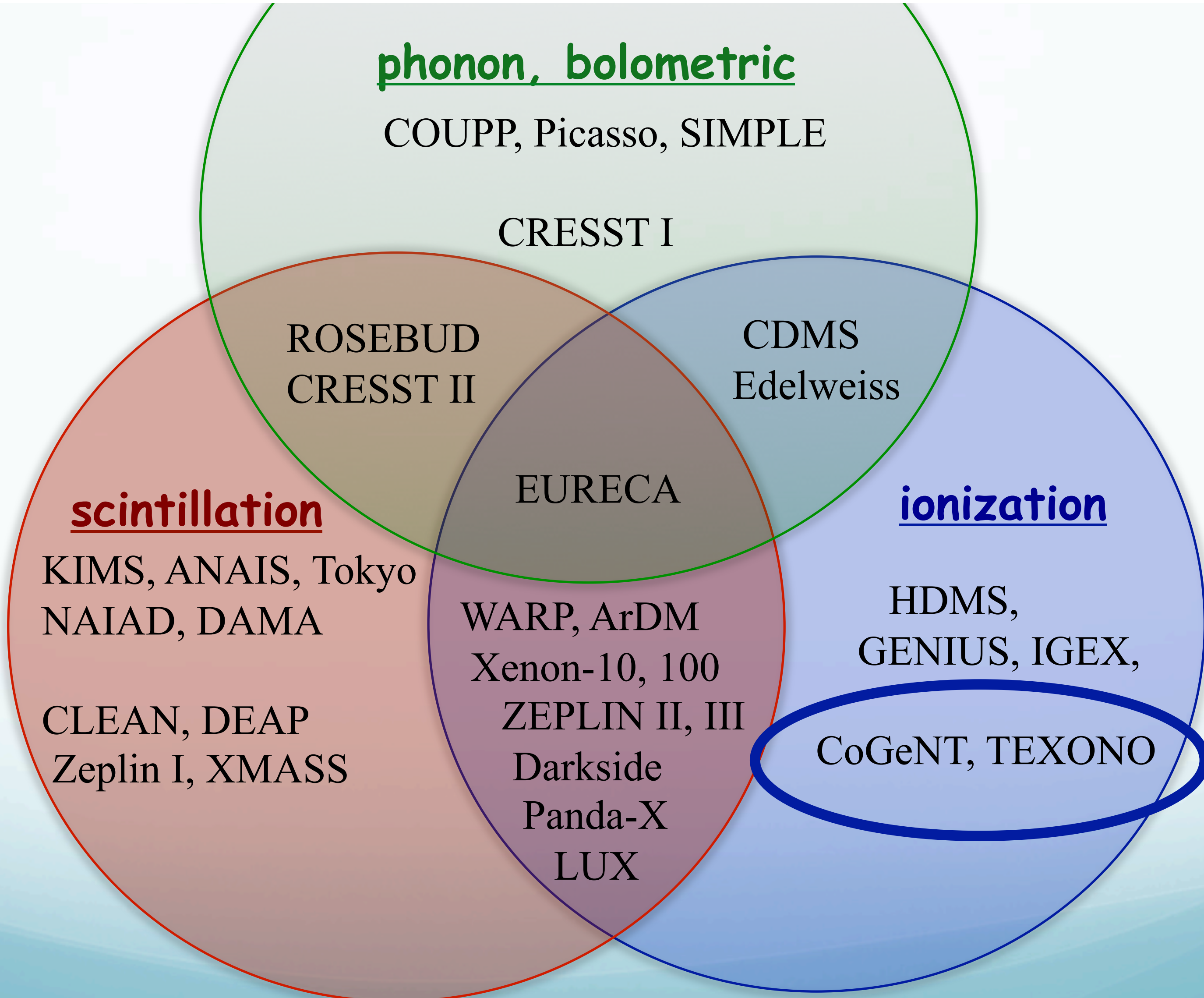
WArP is triple discrimination (like CDMS)



Underground Labs with Noble Liquid DM



Counting Nuclear Recoils: Sometimes one mode is enough

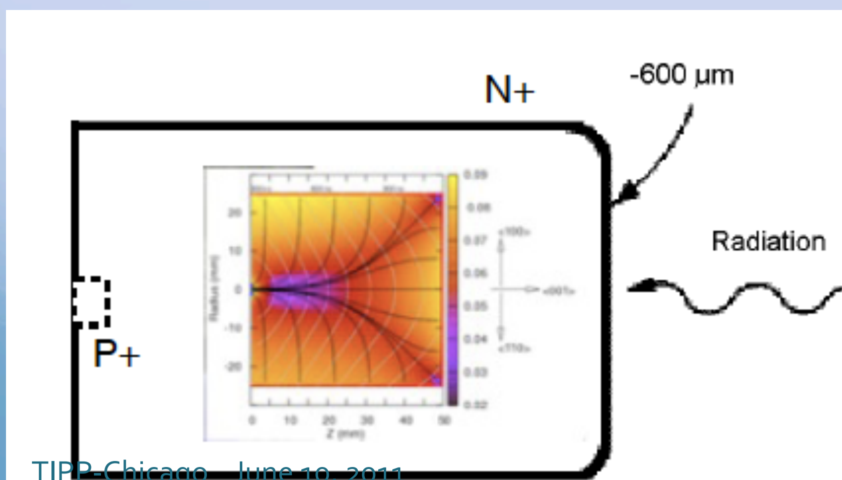


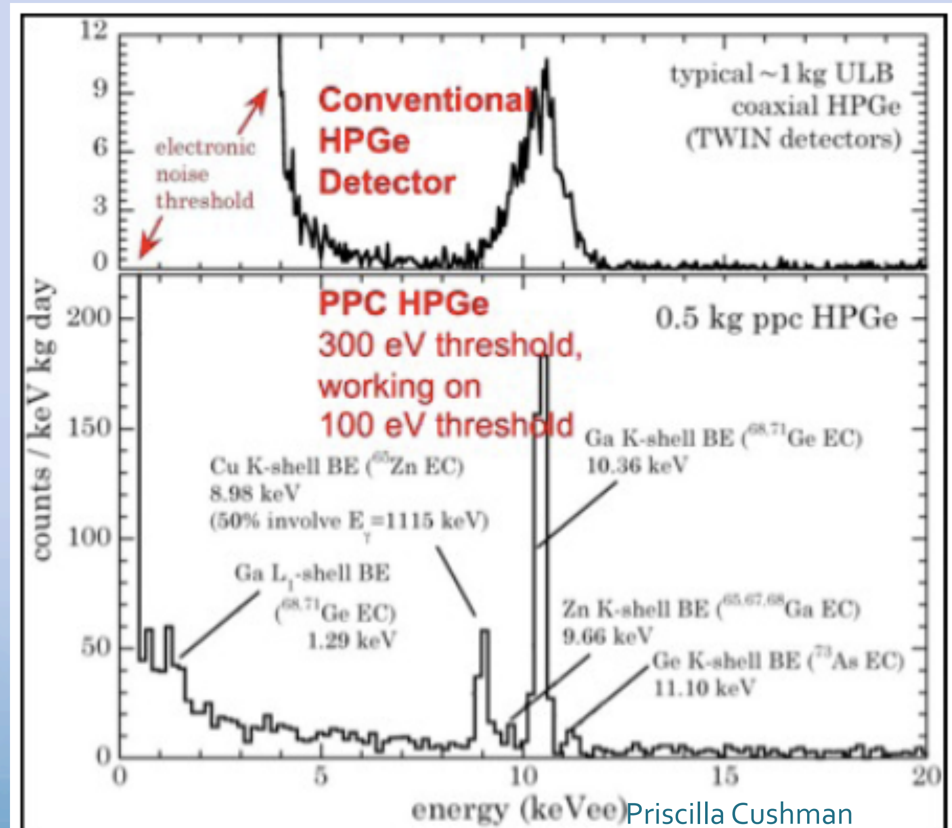
High Purity Germanium

* Excellent energy resolution
* Mostly used for neutrino experiments
* Also can do neutrinoless double beta decay detectors

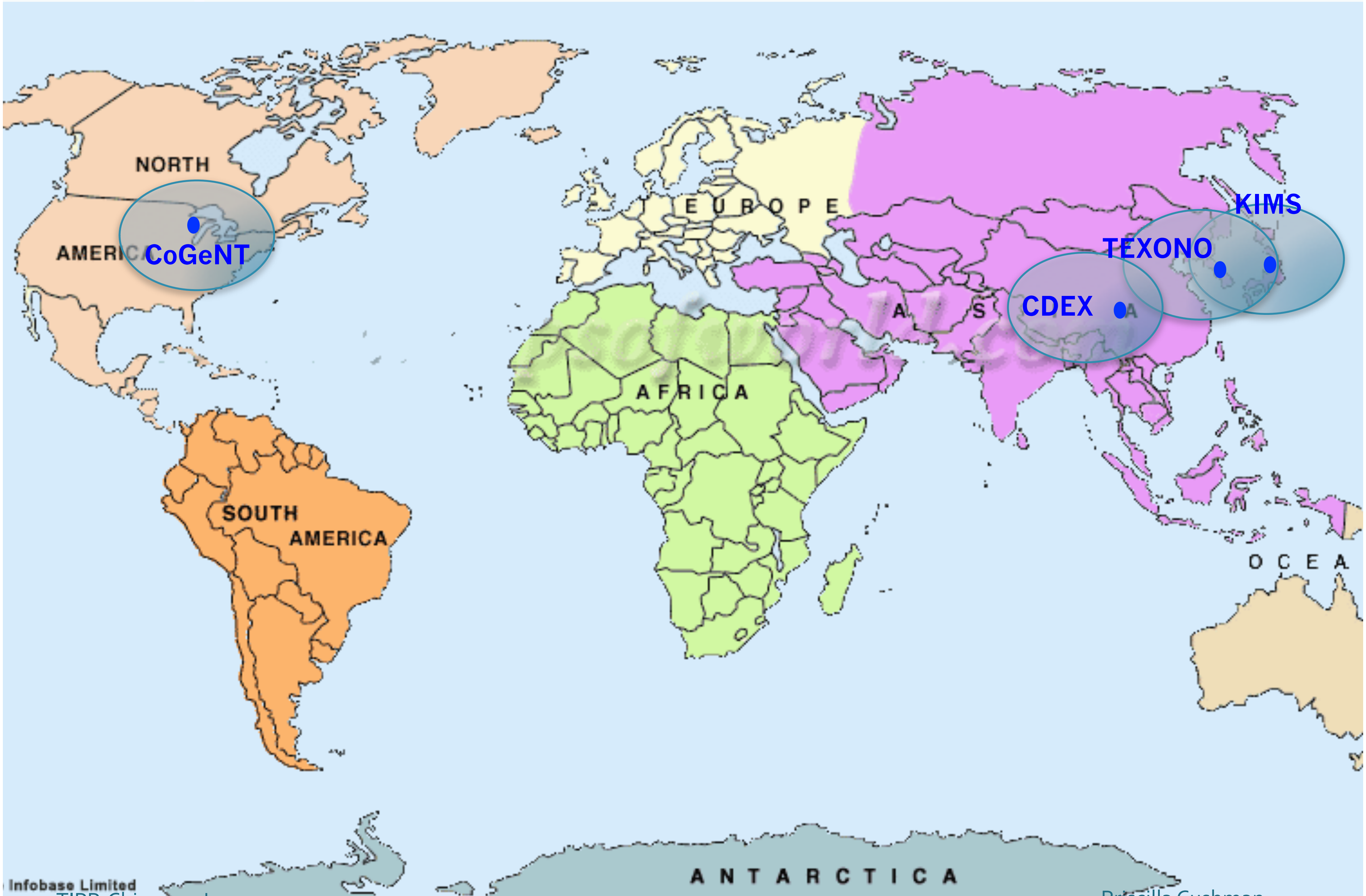
Use **energy resolution**
to beat down background
No evt by evt ER vs NR discrimination
Some pulse shape discrimination

Window of opportunity: can go to
very low thresholds with new
low capacitance configurations

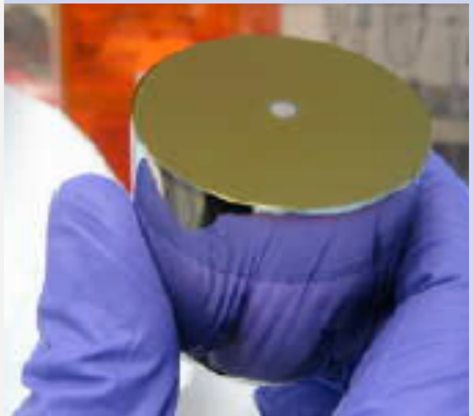




Underground Labs with low threshold HPGe



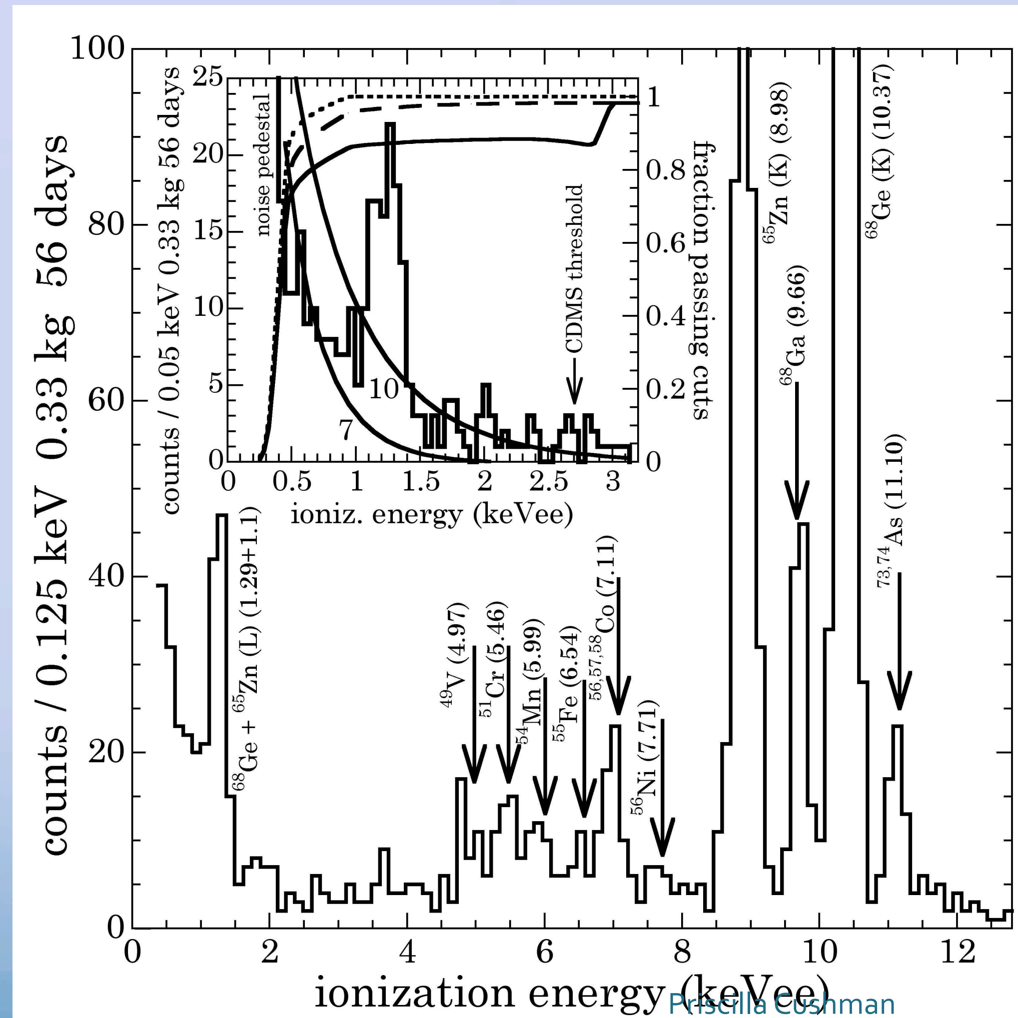
High Purity Germanium: CoGeNT



Continue to develop the P-type point contact HPGe

ββ0ν (Majorana)
ν detector
DM detector

Aalseth et al., arXiv:1002.4703



High Purity Germanium: CDEX/TEXONO

CDEX (China Dark matter EXperiment) at new Jin-Ping Lab
Merging of collaborations and technologies

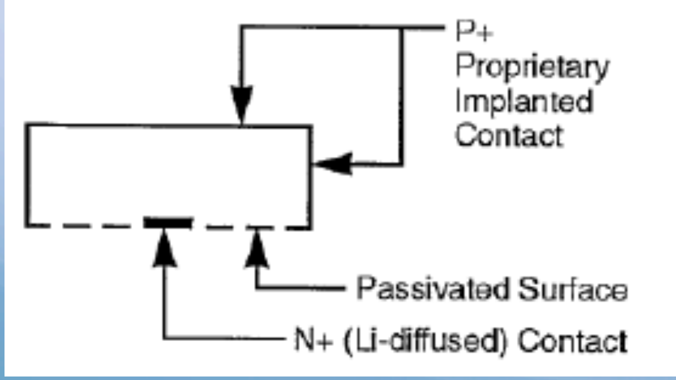
TEXONO (Taiwan EXperiment On neutrinO) at Kuo Sheng Reactor

ULB-HPGe (1 kg)
CsI(Tl) (200 kg)
ULE-ULB-HPGe (20g)

[1] Magnetic Moment search at ~ 10 keV range → [PRD 75 2007].
[2] $\sin^2\theta_W$ measurement at ~ MeV range → Results will be published.
[3] WIMP Search at sub keV range → [PRD 79 2009].
[3] $\bar{\nu}_e$N Coherent Scattering → Goal.

DM search moves to JinPing (China, India, Turkey, TEXONO, KIMS)

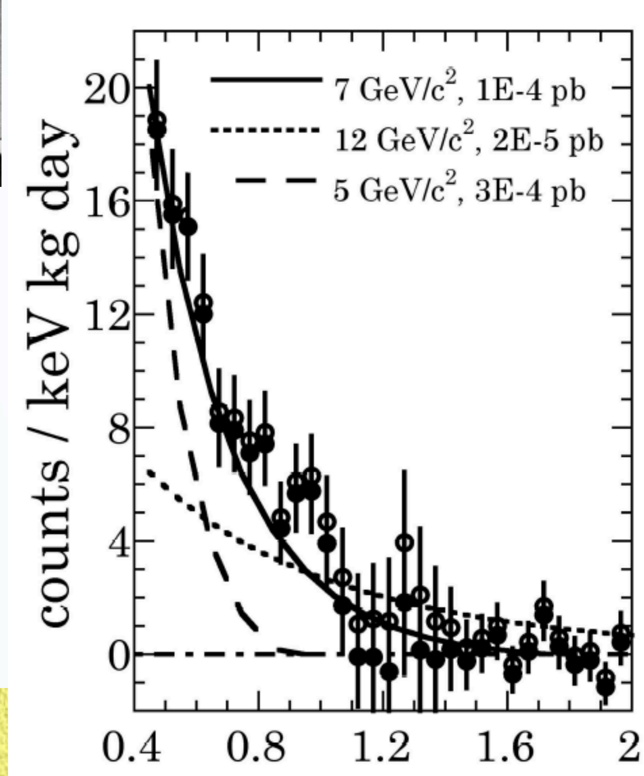
4 x 5g **ULEGe**



500g and 900g PCGe detector

E_{thr} (50% eff) 200-300 eV.
Eventual exposure up to 100 kg-d

Snapshot: improved HPGe technology



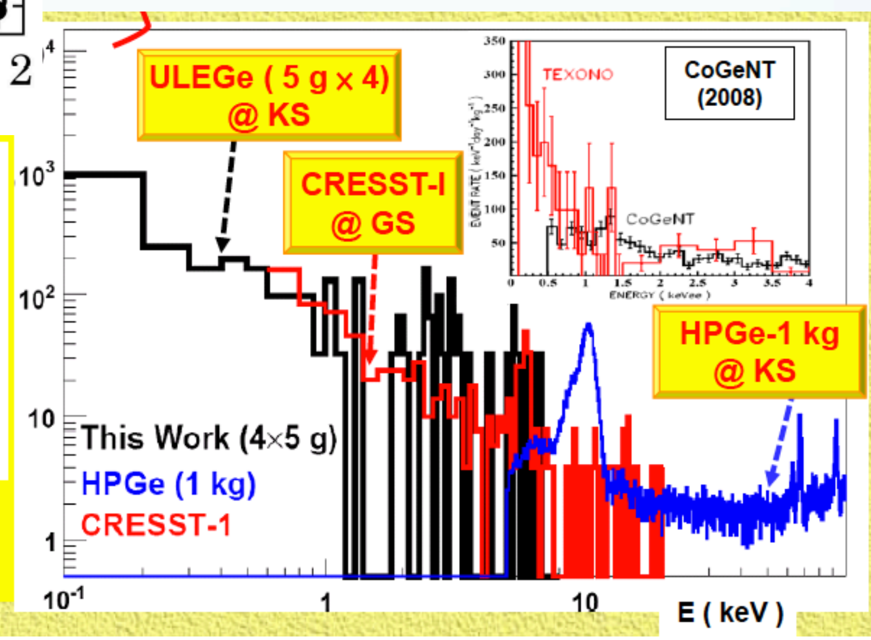
CoGeNT sees exponential excess at low energies

arXiv:1106.0650

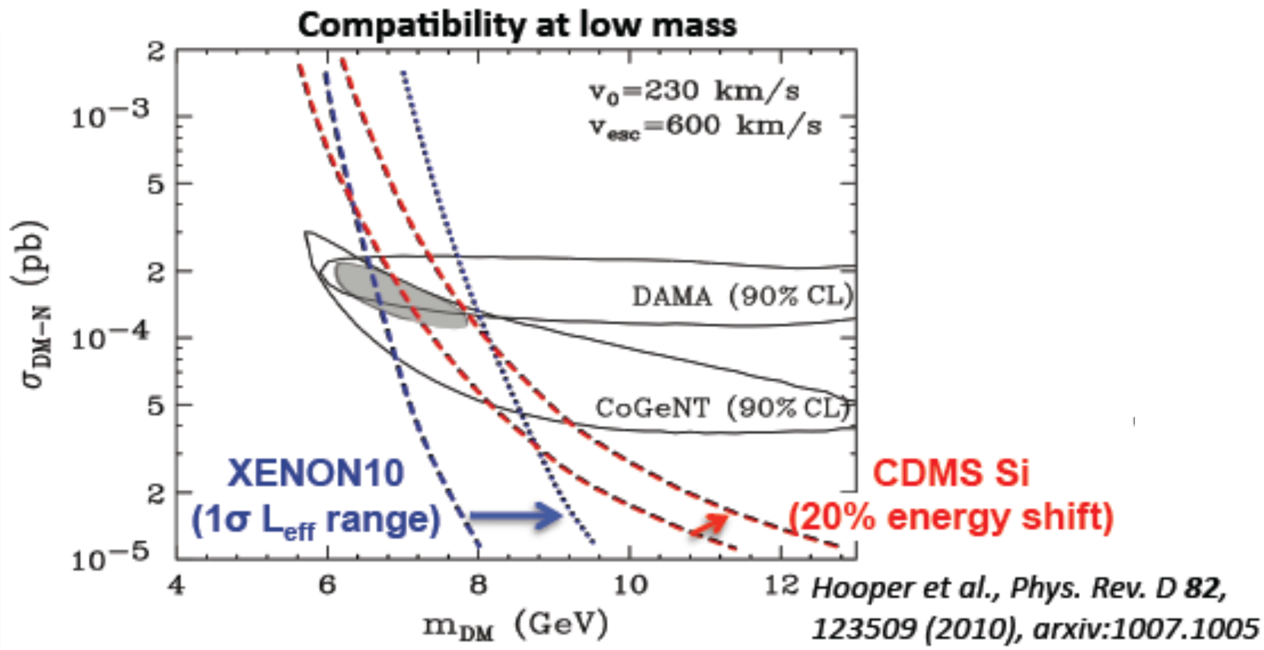
So does **TEXONO**, **but** their claim = not yet ready to do DM run at new deep site

sub-keV Background :

- **Not fully explained with conventional background modeling**
- **Intense work on hardware, software and data taking at new underground site**



Why all the excitement?
Low mass WIMPs promise DAMA compatibility



Hooper et al., Phys. Rev. D ***82****, 123509 (2010), arxiv:1007.1005*

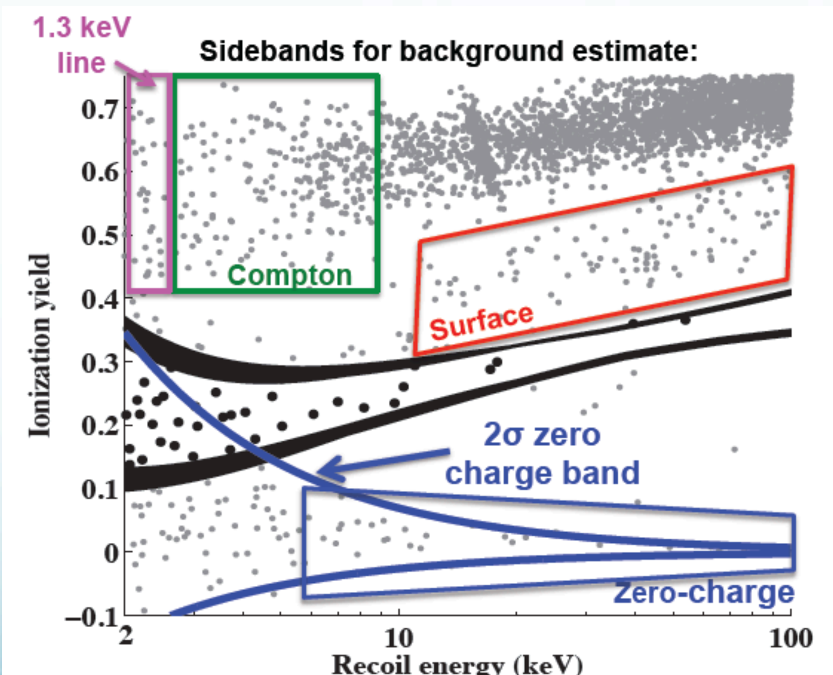
Low energies more vulnerable to

- Uncertainties in astrophysics (e.g. halo properties)
- Uncertainties in L_{eff} (NR:ER scintillation efficiency)
- Uncertainties in Energy Scale

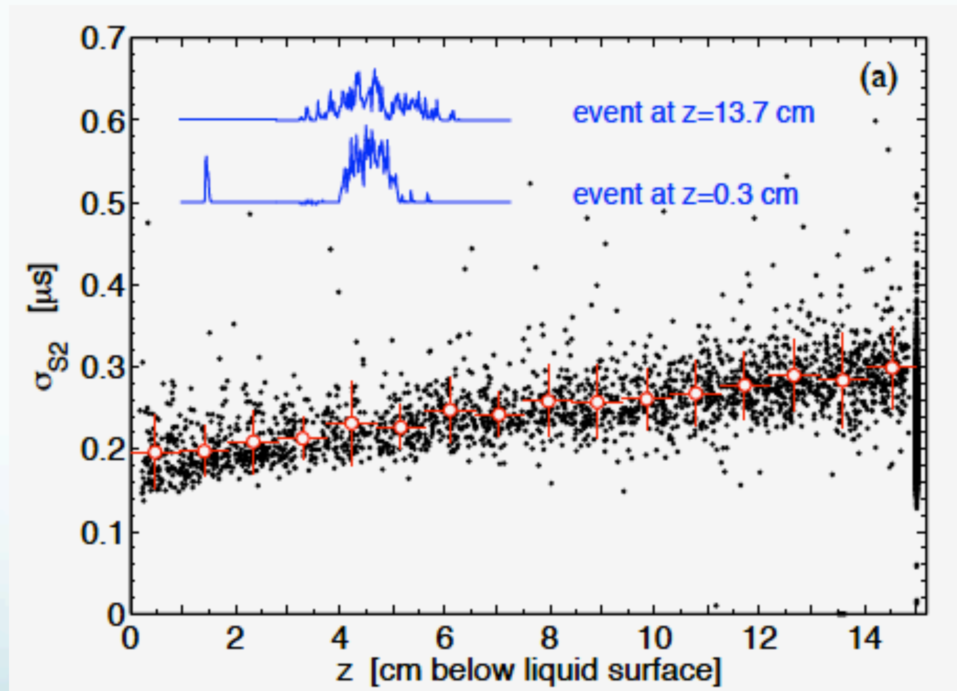
CDMS & XENON push to lower thresholds

Relaxing the NR discrimination

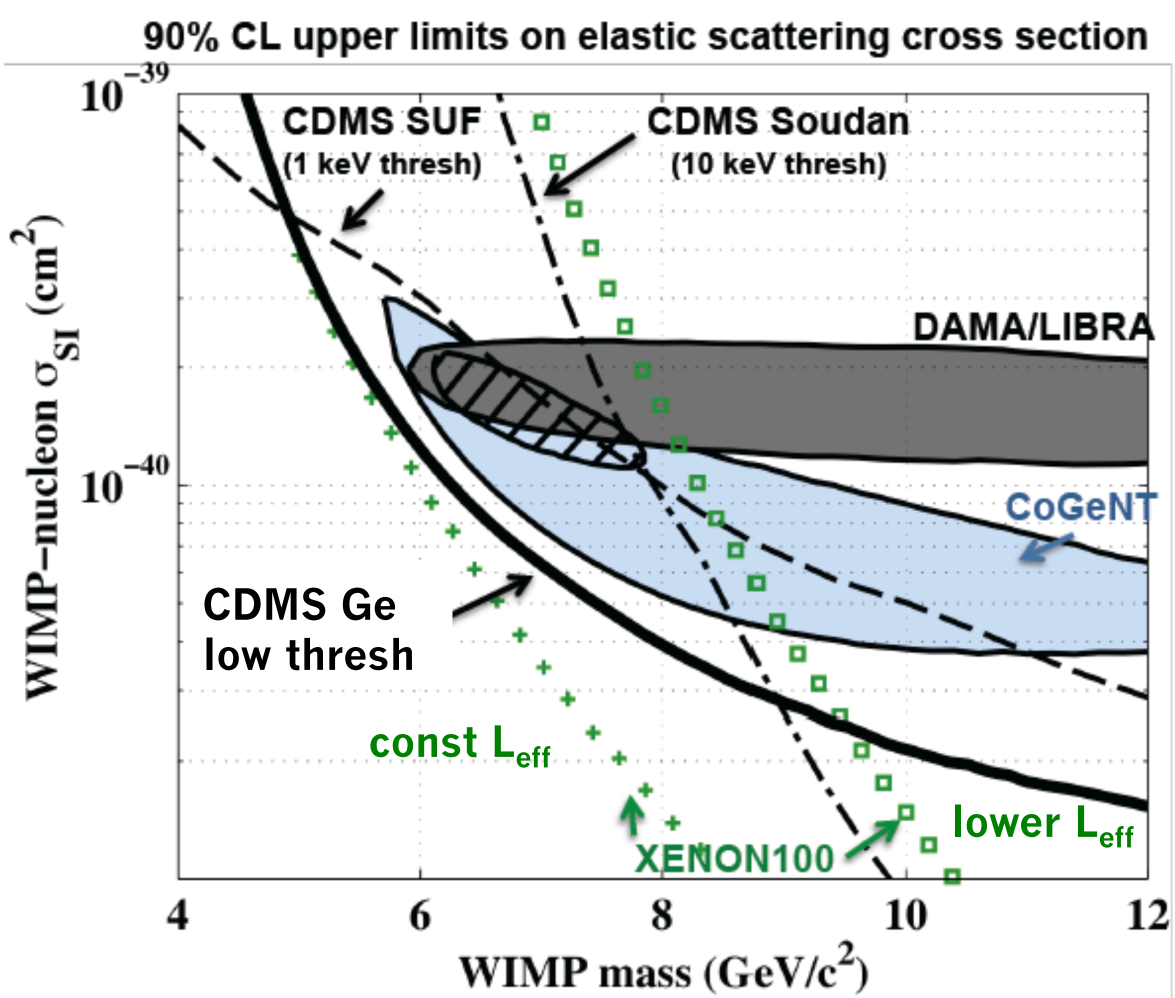
CDMS gives up ionization signal
(except for "drift heating" correction)



XENON gives up prompt scint (S1)
Makes fiducial cuts via S2 width



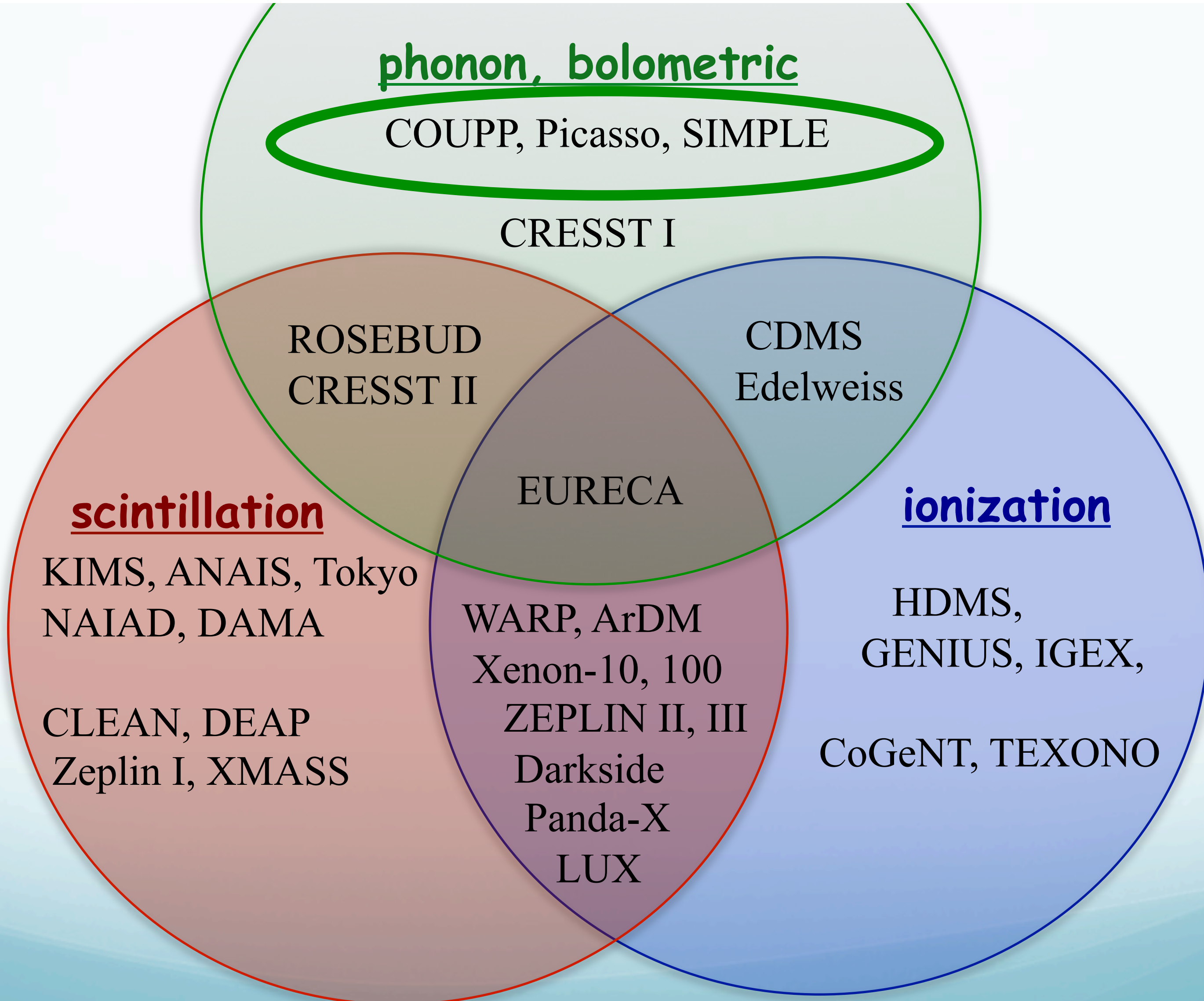
New CDMS & XENON limits exclude overlap region



Ahmed et al. PRL 106, 131302(2011) , arXiv:1011.2482

Akerib et al., PRD 82, 122004 (2010), *arXiv:1010.4290*

Counting Nuclear Recoils: Sometimes one mode is enough



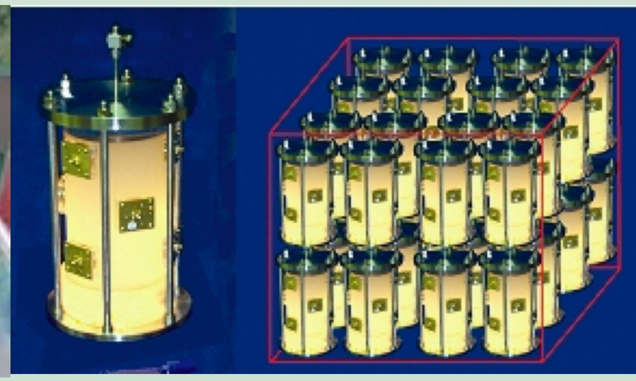
Threshold Detectors: Insensitive to ER altogether!

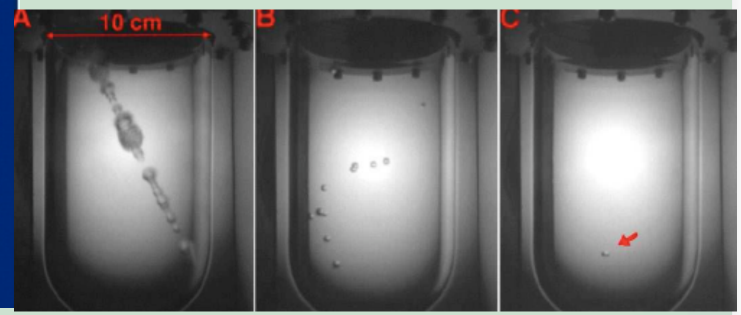
Nucleation Threshold determined by T, P ➔ insensitivity to γ, β
Fill with a flurocarbon: Emphasis on spin-dependent limits via ^{19}F

Neutron dosimeter technology

Bubble Chamber

MIP Multiple NR Single NR





SIMPLE (Bas Bruit)

1-4 % suspension of superheated C_2ClF_5 droplets in gel.
shielded pool, shallow

PICASSO (SNOLab)

0.5% C_4F_{10} droplets
in water-based gel
piezoelectric transducers

COUPP (SNOLab)

Superheated bubble chamber
CF_3I, multiple targets
CCD camera (+ acoustic)

Spin Dependent Cross Sections

Couples to net nuclear spin J_N

$$\sigma_{SD} = \frac{32}{\pi} G_F^2 \frac{m_\chi^2 m_N^2}{(m_\chi + m_N)^2} \frac{J_N + 1}{J_N} \left(a_p \langle S_p \rangle + a_n \langle S_n \rangle \right)^2$$

Very dependent on material. Need multiple experiments to explore parameters
*WIMP capture rate in sun (**proton** scattering) gives good indirect limits*

neutron coupling

CDMS, EDELWEISS

^{73}Ge (7.73%) *odd n with J = 9/2*
or **90%** *for enriched (**CDEX/TEXONO**)*
^{29}Si (4.68%) *odd n with J = 1/2*

Xenon100,XMASS, etc.

^{129}Xe (26%) $\langle S_n \rangle = .359$ $J=1/2$
^{131}Xe (21%) $\langle S_n \rangle = -.227$ $J=3/2$

proton coupling

CRESST phonon (Al_2O_3)

^{27}Al $\langle S_p \rangle = .343$ $J= 5/2$

DAMA/LIBRA, NAIAD, ANAIS (NaI)
KIMS (CsI)

^{127}I $\langle S_p \rangle = .309$ $J=5/2$
^{23}Na $\langle S_p \rangle = .248$ $J=3/2$
^{133}Cs $\langle S_p \rangle = -.370$ $J=7/2$

proton & neutron coupling

Tokyo CaF_2(Eu) **PICASSO** C_4F_{10} **SIMPLE** $C_2Cl\,F_5$ **COUPP** CF_3I

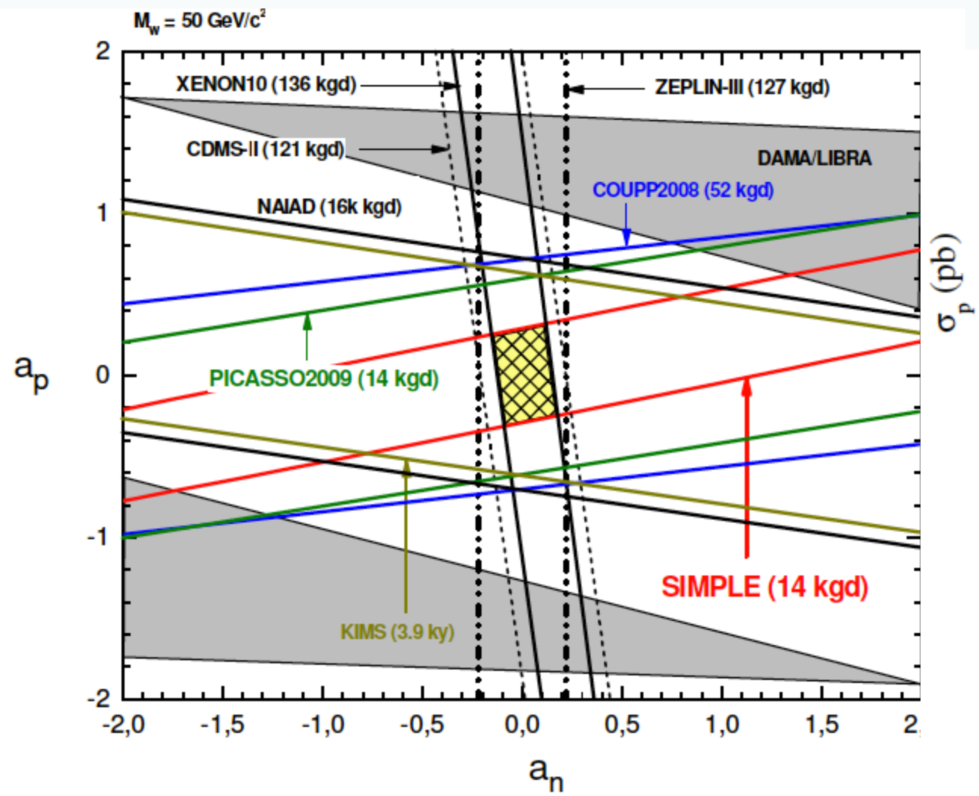
^{19}F (% depends on fluorocarbon mixture used)
$\langle S_n \rangle = -.109$ $\langle S_p \rangle = .441$ $J=1/2$

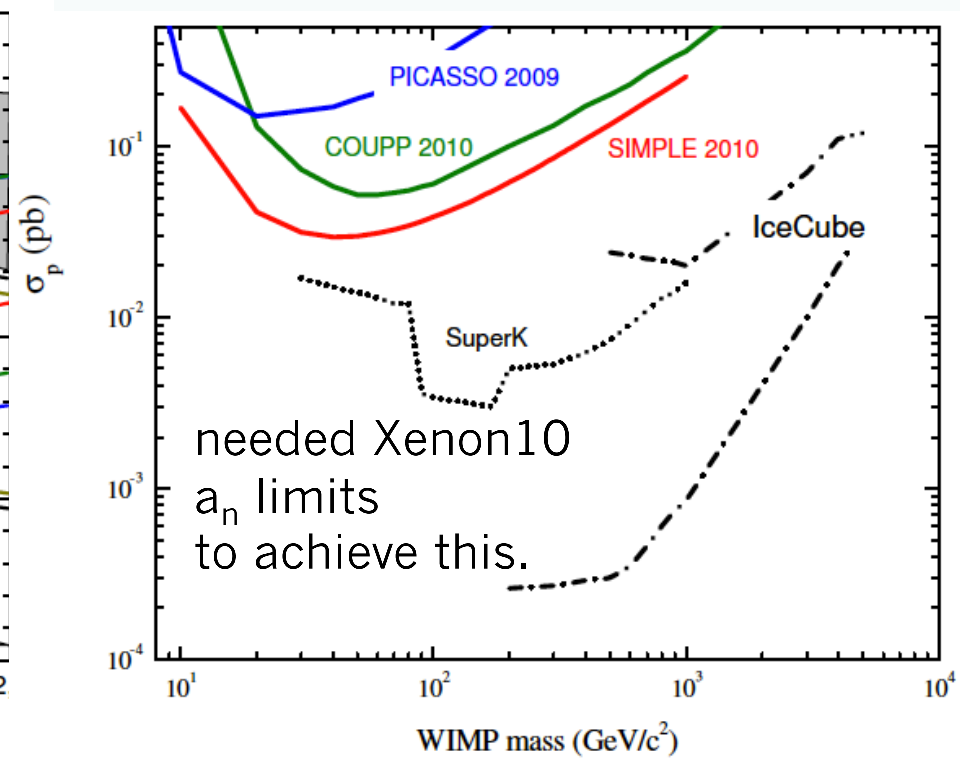
Snapshot: SIMPLE pulls ahead

New SD limits (*14.1 kg-d*) using 15 superheated droplet detectors with total active mass of 0.208 kg.

x10 reduction in acoustic noise: piezoelectric transducer ➔ improved microphone and adaptive electronics.

$|a_p| < 0.32$, $|a_n| < 0.17$ for 50 GeV/c^2 WIMP



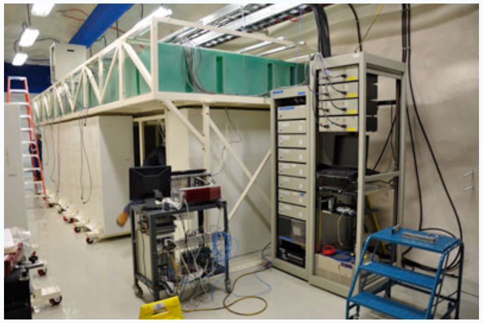


needed Xenon10 a_n limits to achieve this.

COUPP & PICASSO right behind

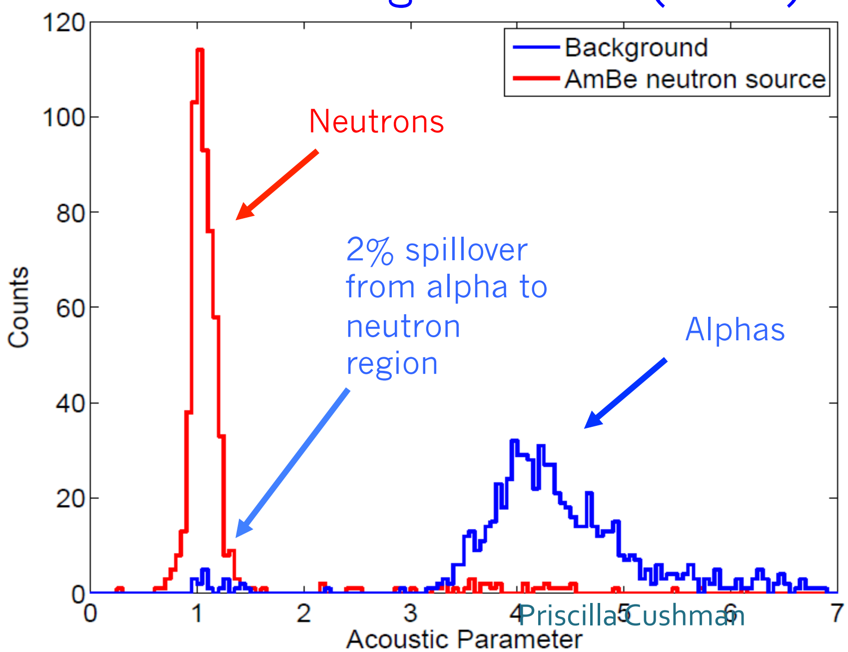
new installations with water shields at SNOLab

PICASSO: 32 detector modules
with an active mass of 2.6 kg
Extensive bubble formation &
acoustic discrimination studies



COUPP 4 kg CF_3I chamber moved from FNAL
Stable running @ 79% livetime since Nov 2010
>98% acoustic α rejection
..... stay tuned!

COUPP 60 kg bubble chamber
undergoing tests.
Running in NUMI (FNAL)



Challenges for Threshold Detectors

Backgrounds: alphas and neutrons

Alphas from materials and radon plateout on vessels

Make a Fiducial cut: spatial localization

arrays of microphones or CCD cameras

Improving α:n discrimination

SIMPLE: α bkgd < 0.5 evt/kg/d.
U/Th contaminations in the gel, measured at ~ 0.1 ppb

COUPP α bkgd ~5.3 evt/kg/d (^{222}Rn from leaky valve? can be reduced)
1 n/day from 8 piezoelectric transducers (replace this summer)

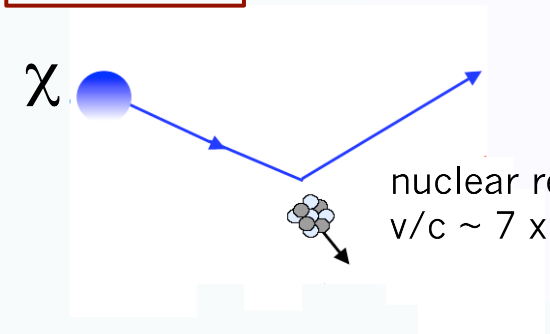
Scaling up

Bubble chambers can deploy larger masses more easily than SDD

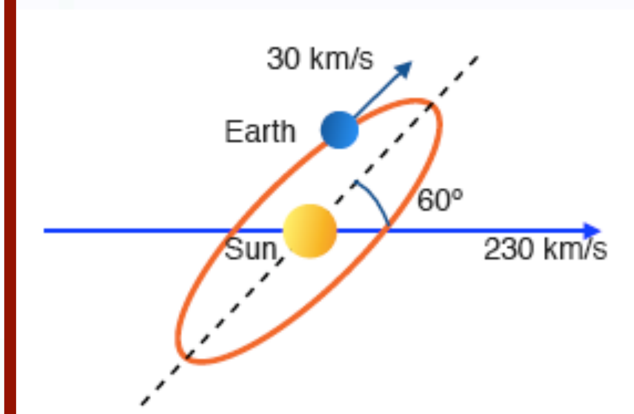
But who will win the acoustic discrimination contest?

Choose your Technique

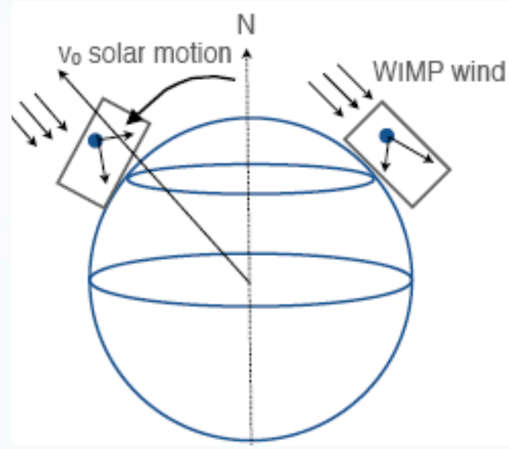
Signal



Count nuclear recoils



annual flux variation



diurnal directional modulation

Background

Doesn't require event by event background rejection,

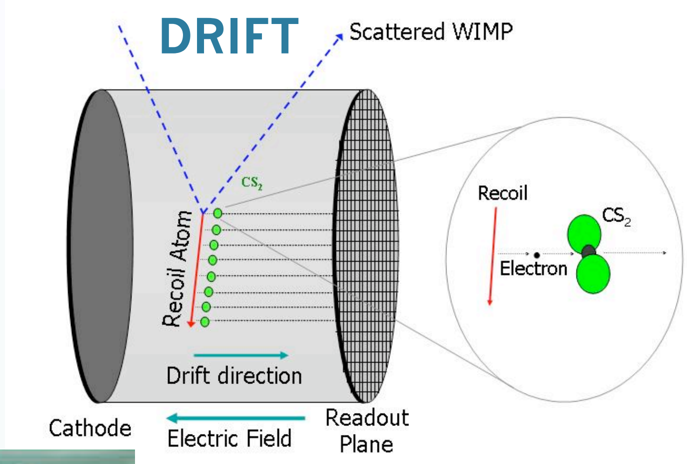
but WITHOUT it, detailed systematics studies are required

Diurnal Directional Modulation

Robust Signature – Promises WIMP astronomy!

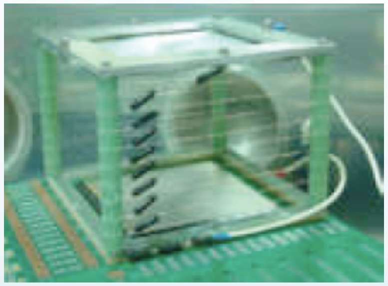
large modulation (20-50%), rather than 3% for annual sidereal – hard to fake it with bkgd

To see tracks or head-tail difference ➔ gas target
But gas targets need to be big (compared to solid)



DRIFT II (running – Boulby)
Competitive SD limits
Negative ion TPC w/ MWPC readout
CS_2 molecule (less diffusion)

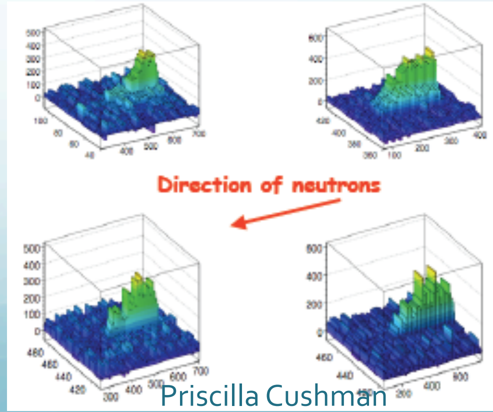
NEWAGE (test cell at Kamioka)
Ar + C_2H_6 micro-TPC
microdot charge readout



MIMAC (test chamber CEA- Saclay)
^{3}He or CF^4 micro-TPC

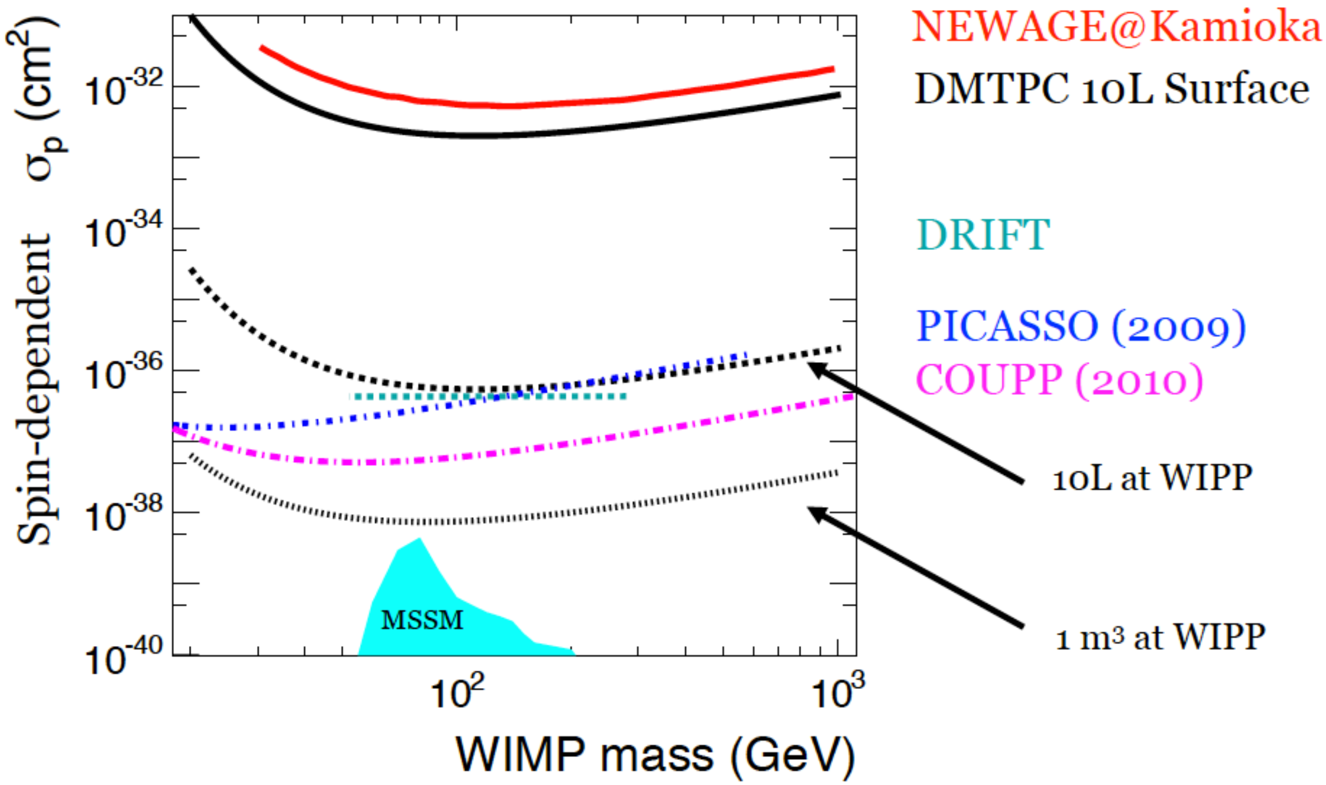
DMTPC (test chamber – MIT, WIPP)
CF_4 low pressure TPC with optical readout

DMTPC head-tail



Snapshot:
SD Limits and Diurnal Mod. Hopes

DMTPC Future Sensitivity



50 keV recoil threshold
1 year live-time

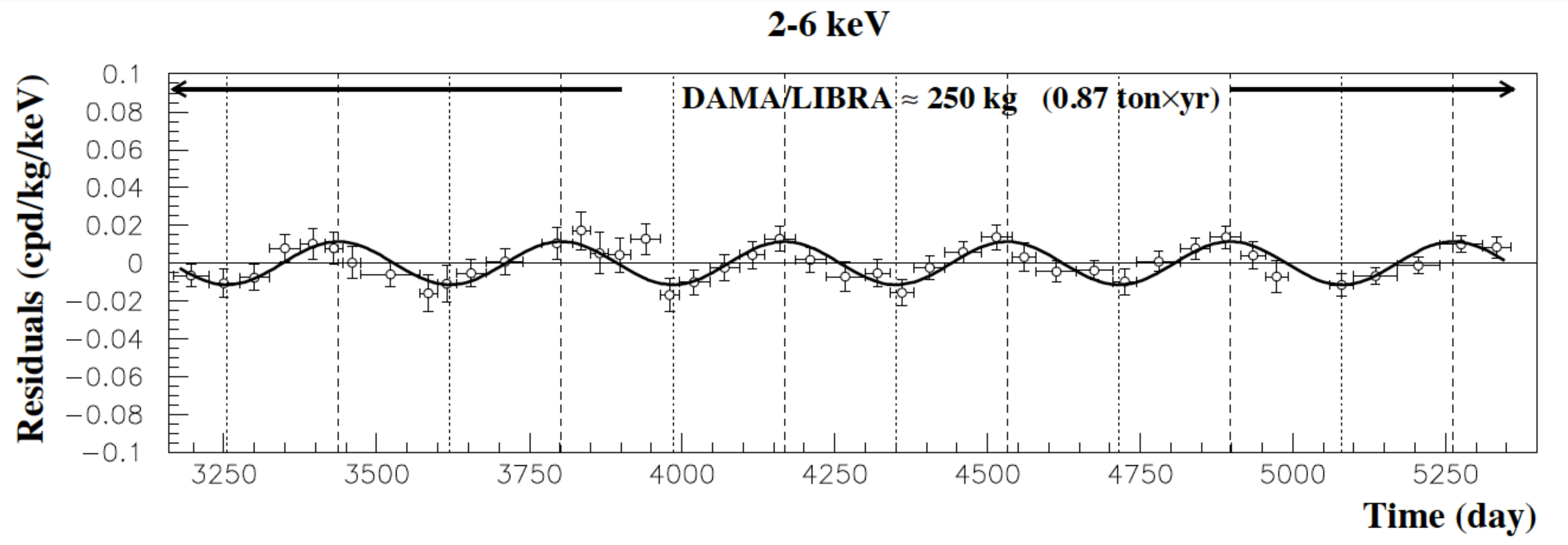
James Battat, MIT

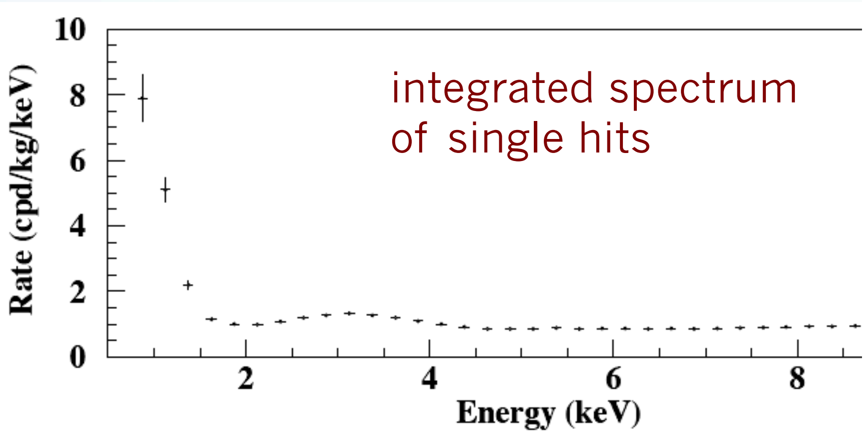
Annual Flux Variation

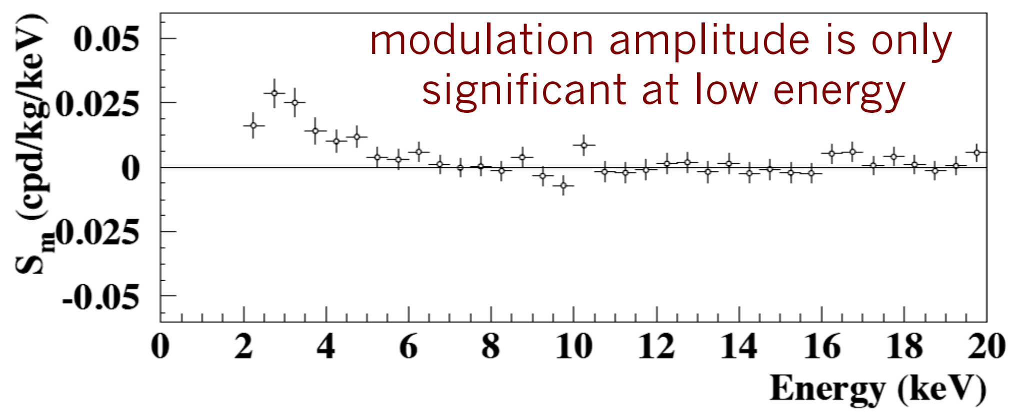
DAMA/LIBRA exposure = 1.17 ton-years of NaI(Tl) at LNGS
25 crystals, each 9.5 kg, running for 6 y in LIBRA (13 yrs total)

Amplitude of a few percent Phase Max on June 2 Significance of 8.9 σ

Annual Flux Variation







Finally, a worldwide effort to check DAMA

Borexino (Gran Sasso)
NaI crystals surrounded by ultra-clean LS
Same Lab
Study backgrounds

ANAIS (Canfranc)
250 kg NaI inside lead/poly shield
DAMA-size array in Different Lab

Requires crystals purities < 1 ct/keV/day
St Gobain has exclusive contract with DAMA
New R&D on NaI purity w/ St Gobain

DM-Ice (South Pole)
250 kg NaI
Different Systematics and environ.

If DAMA signal is astrophysical➔ a 5-sigma measurement in 2 years with 250 kg and comparable background to DAMA.

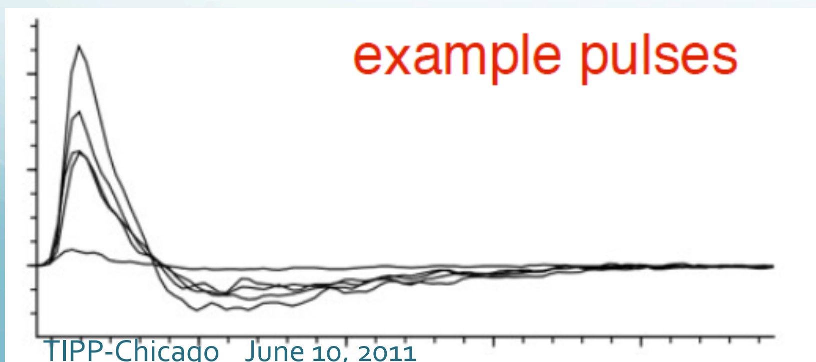
DM-Ice

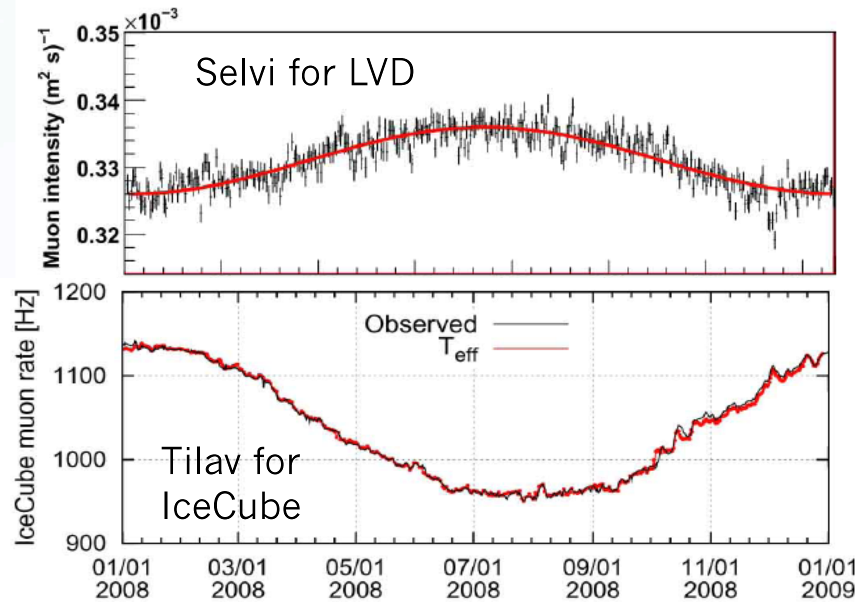
Ann Mod: Same phase if WIMPs,
Opposite phase for most
seasonal backgrounds
No radon or water table fluctuations

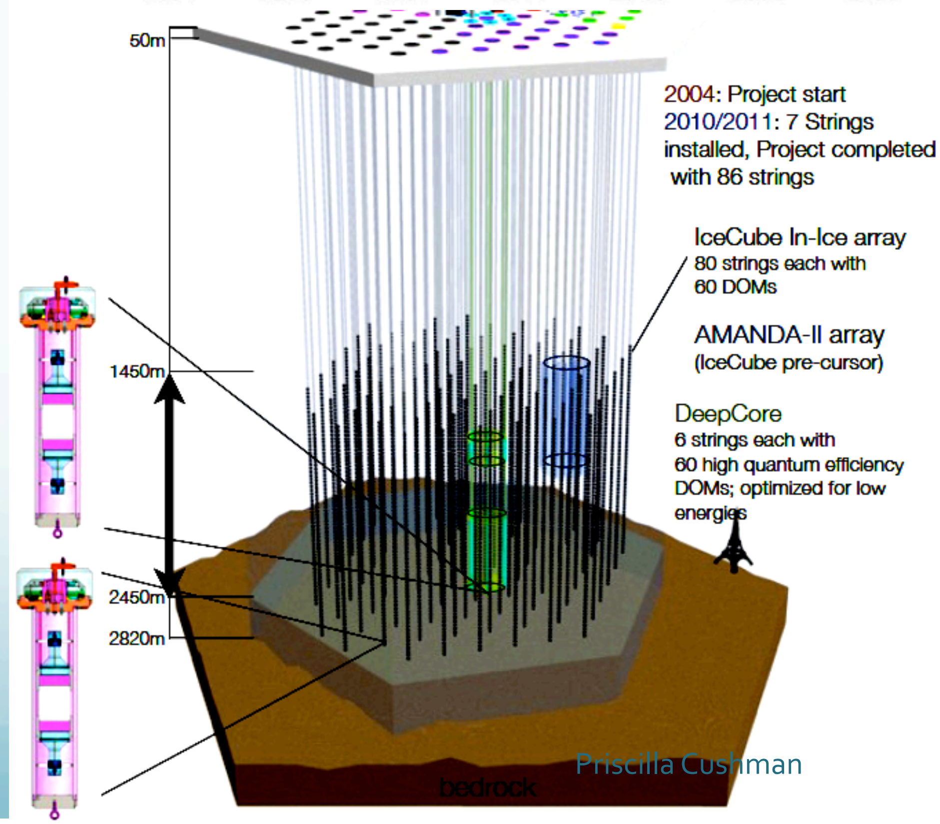
At 2450 m depth, constant T= −20° C
(warmer than a Minnesota winter)

IceCube provides a muon veto,
radiopure shielding
lab infrastructure

Prototype: 8.5 kg NAIAD crystals
(~8 cts/keV/d) at the bottom
of two IceCube strings (Dec 2010)







But Wait! There's More!

Different Crystal

KIMS (Yangyang Lab, Korea)

Published 2007 *Limit*

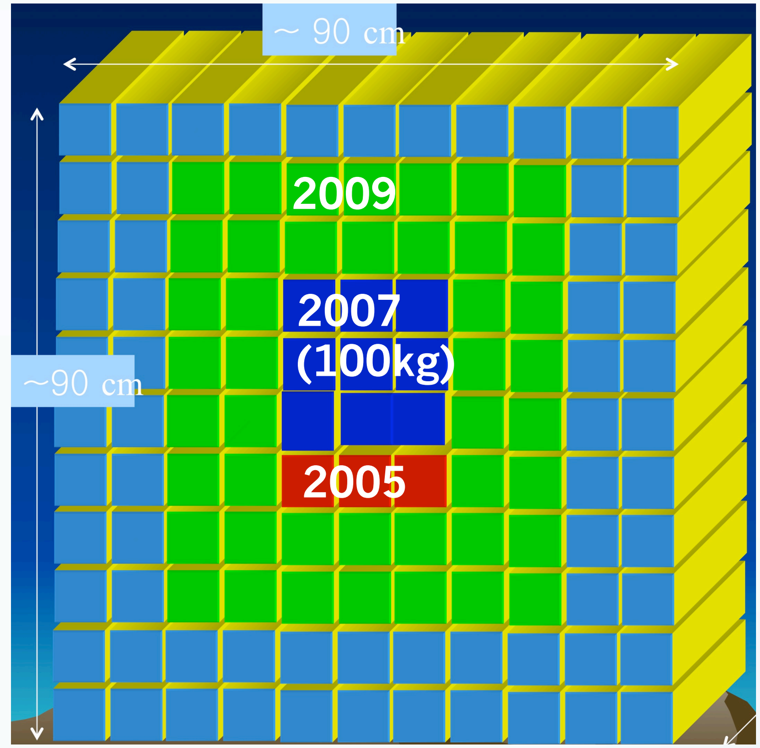
four 8.7 kg CsI(Tl) crystals for 3409 kg-d

pulse shape discrimination

liquid scint veto, 1 dru bkgd

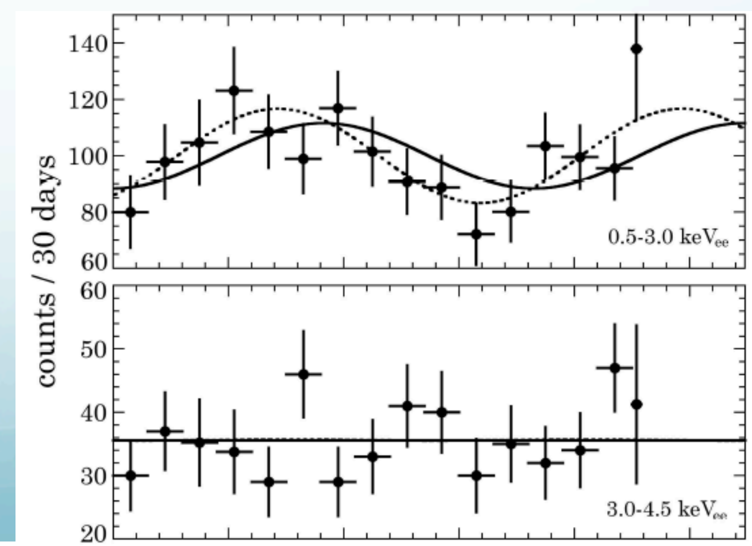
Reduce 137Cs in processing (water)

Reduce 87Rb via repeated recrystallization

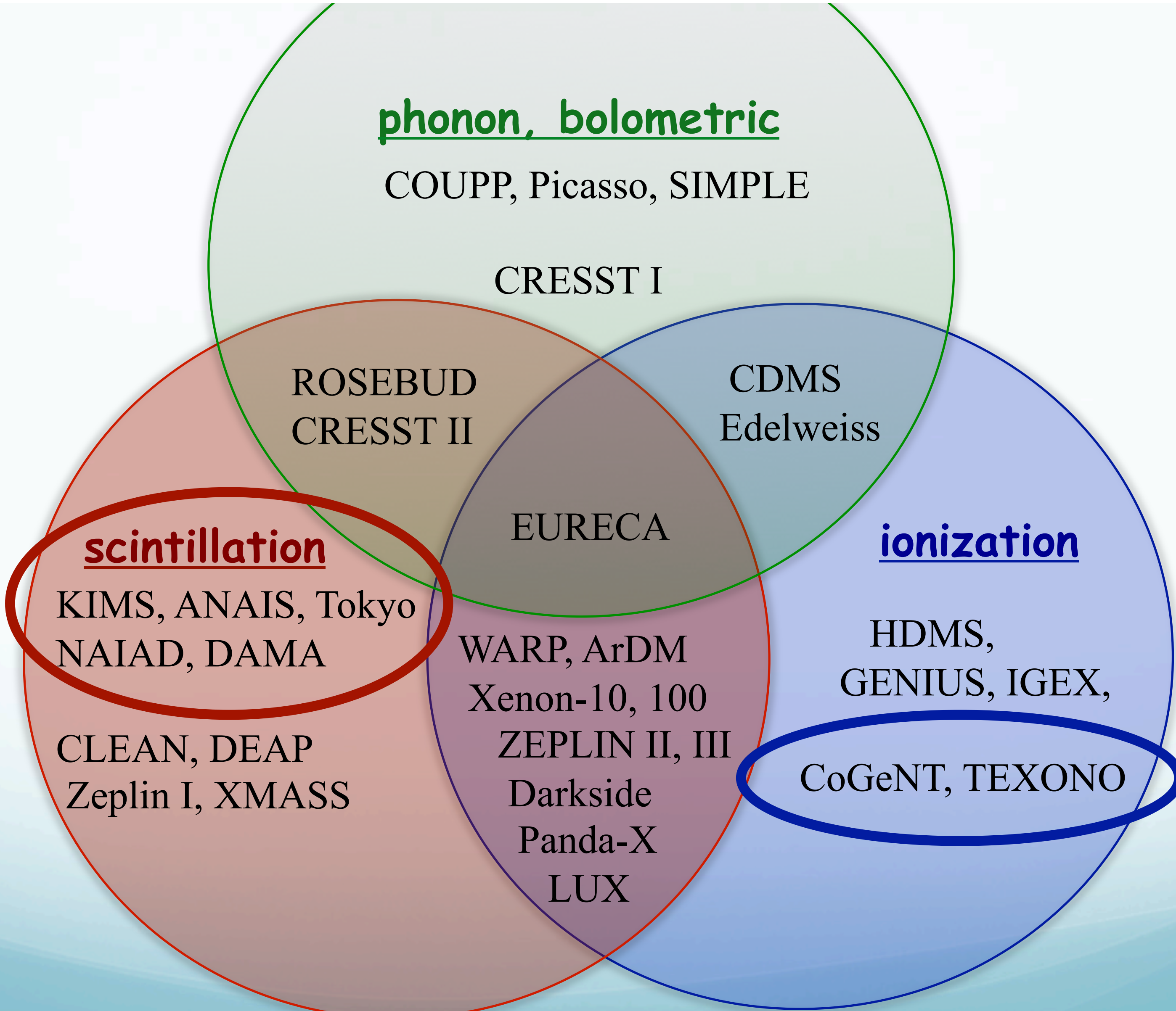


Everyone can look,
but it requires a low threshold
(if DAMA is being checked)

CoGeNT sees a 2.8 σ result
Expect results soon from **Xenon-100, CDMS**



Concentrating on Annual Modulation Reach



Conclusions

A wealth of imaginative detector concepts
And I haven't even mentioned AXION searches

This does NOT mean we need to down-select prematurely!

Different Technologies

New territory → unexplained backgrounds → checks and balance
Compare systematics, Different locations
Any new signal needs multiple confirmation

Different Targets & Different Sensitivities

Once we begin to see WIMPs
Spin dependent or independent? A-dependence
Factor out astrophysical uncertainties
Measure WIMP mass, cross section, explore interaction & astrophysics