Other WIMP Direct Detection Experiments

Jodi Cooley
Southern Methodist University

Outline

- Principles common to experiments
- The Experiments
  - Part 1: The low mass region
  - Part 2: The long standing DAMA/LIBRA experiment
  - Part 3: The search continues...
- Concluding Remarks

World-Wide Experiments

Phonon/Charge/Light:
- CDMS/SuperCDMS
- EDELWEISS
- CRESST

Charge Only:
- CoGeNT/C4
- TEXONO
- CDEX
- CDMSlite

Multi-purpose:
- Majorana Demonstrator
- COURE-0/COURE

Modulation:
- DAMA/LIBRA
- DM-ICE
- KIMS
- ANAIS
- SABRE
- KamLAND-PICO

Bubble Chambers/Superheated:
- PICASSO
- COUPP
- PICO

Directional:
- DRIFT
- DM-TPC

Other:
- DAMIC
- NEXT

*Experiments in red are presenting results or status in parallel sessions.

World-Wide Experiments

Phonon/Charge/Light:
CDMS/SuperCDMS
EDELWEISS
CRES

Modulation:
DAMA/LIBRA
DM-ICE

Directional:
DRIFT
DM-TPC

Charge (
CoGe
TEXO
CDEX
CDMS

er:
AMIC
EXT

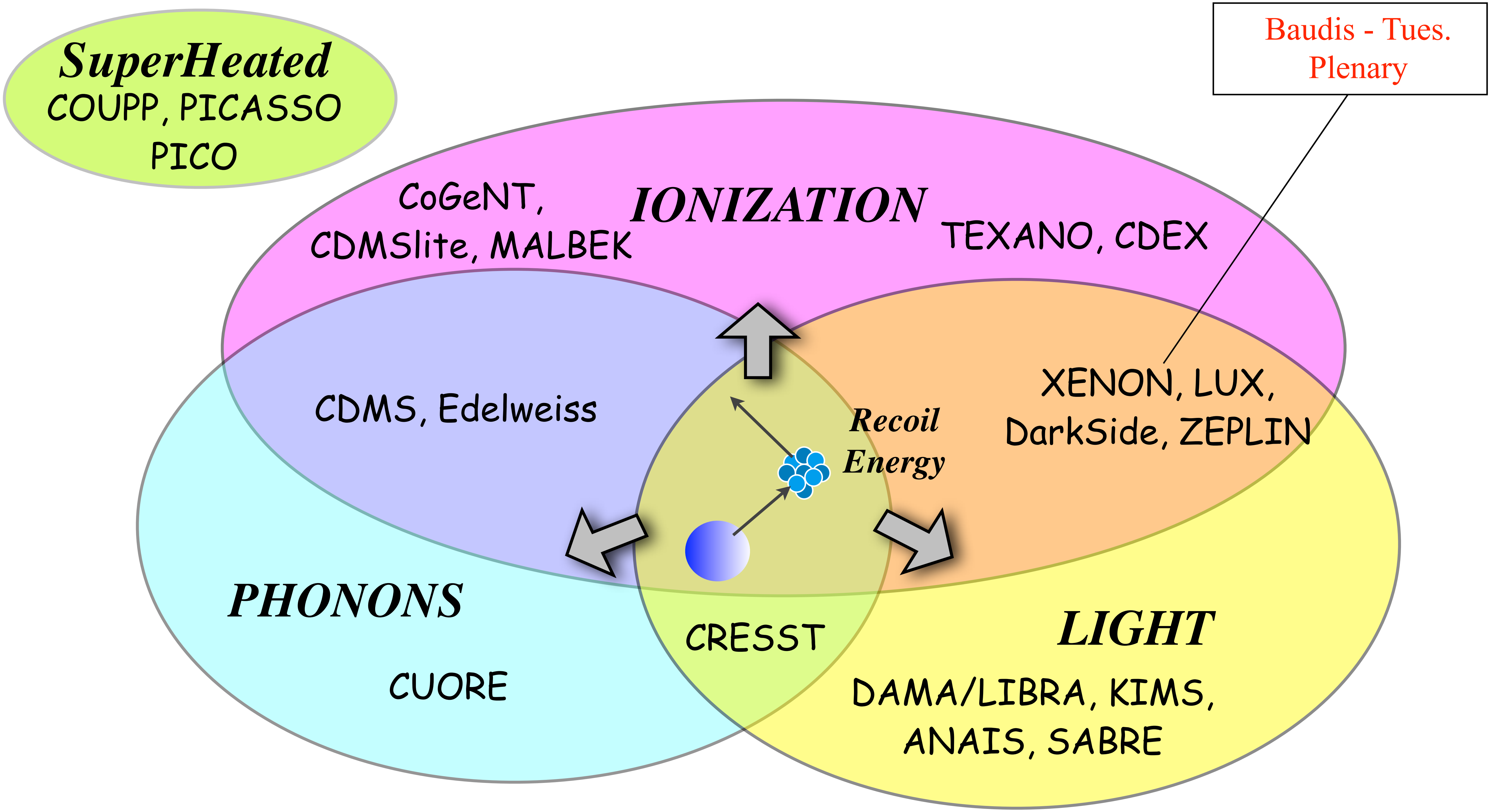
eated:
PICASSO
COUPP
PICO-lite

Too Many Experiments, Too Little Time - My Apology for not Covering All

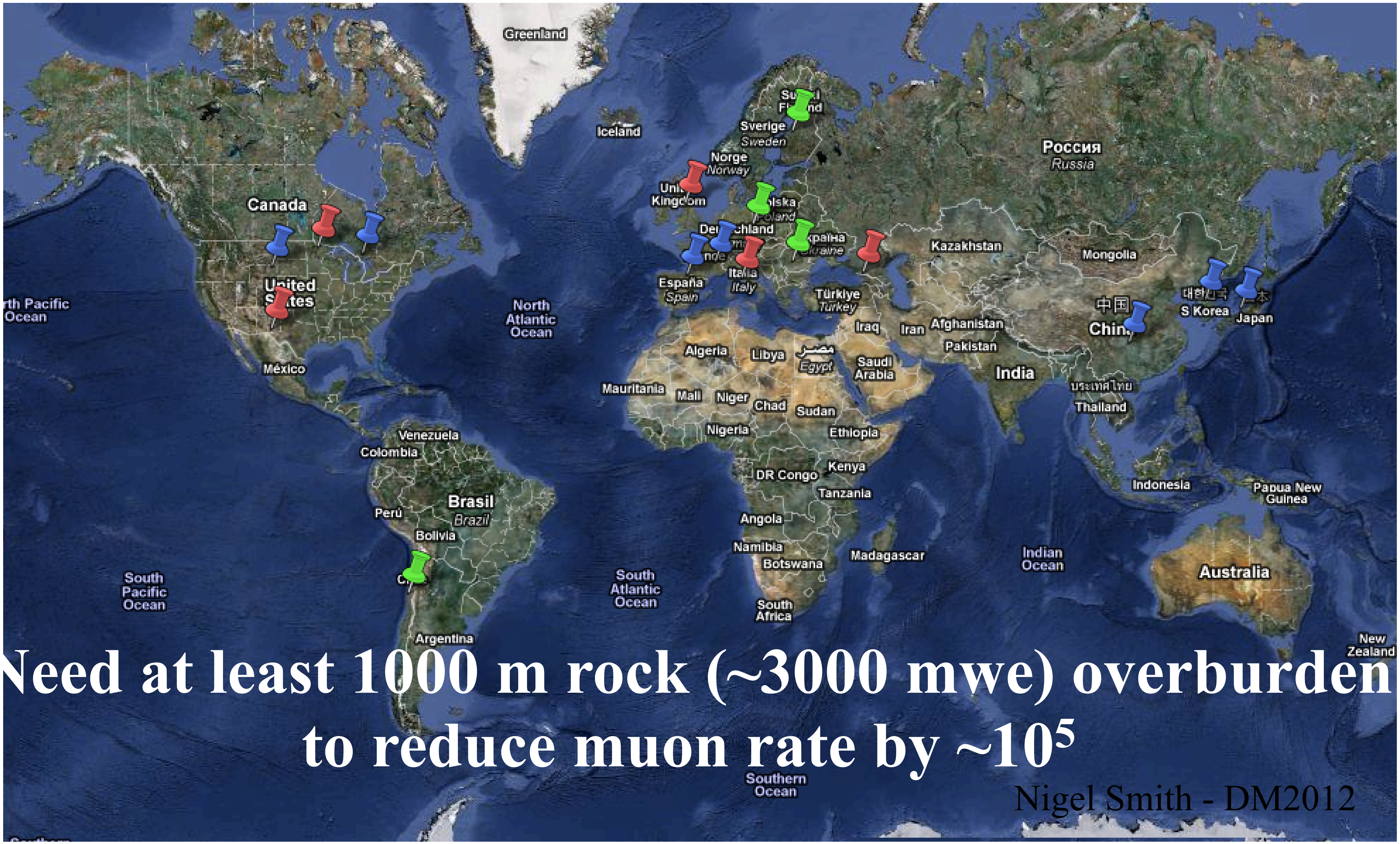
Multi-purpose:
Majorana Demonstrator
COURE-0/COURE

*Experiments in red are presenting results or status in parallel sessions.

Direct Detection



Minimize Backgrounds



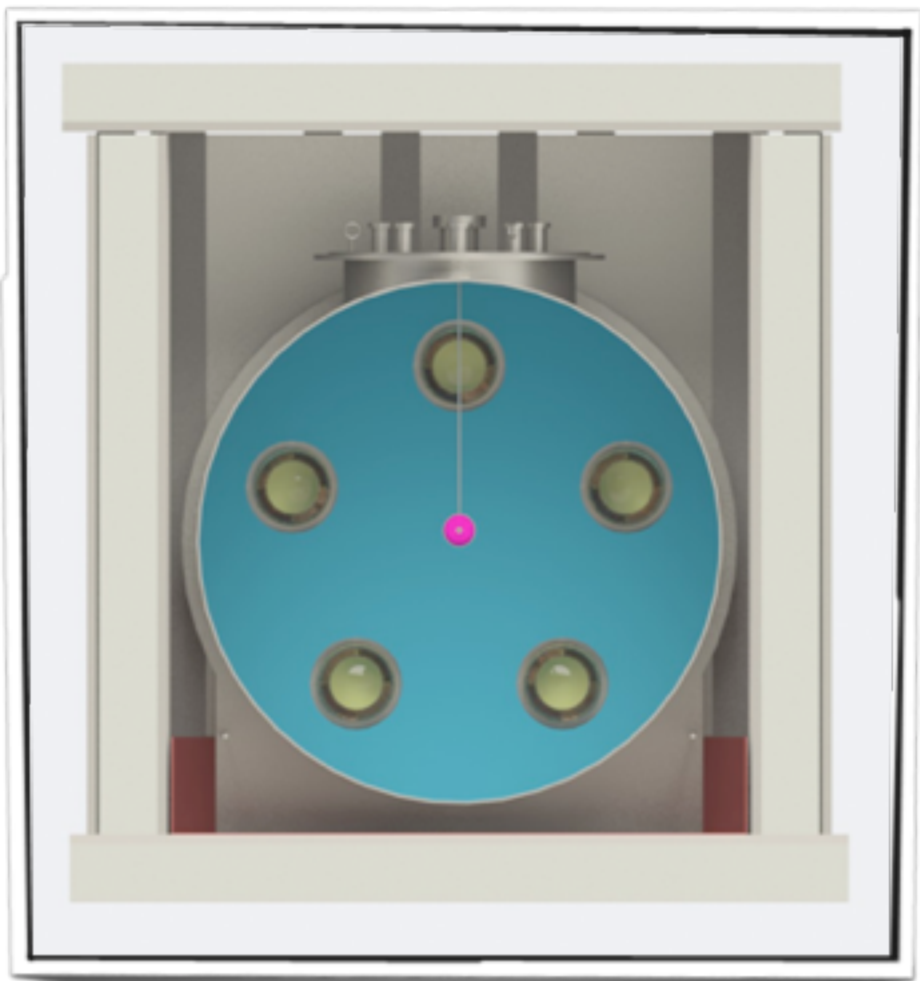
Site experiments underground.

Minimize Backgrounds

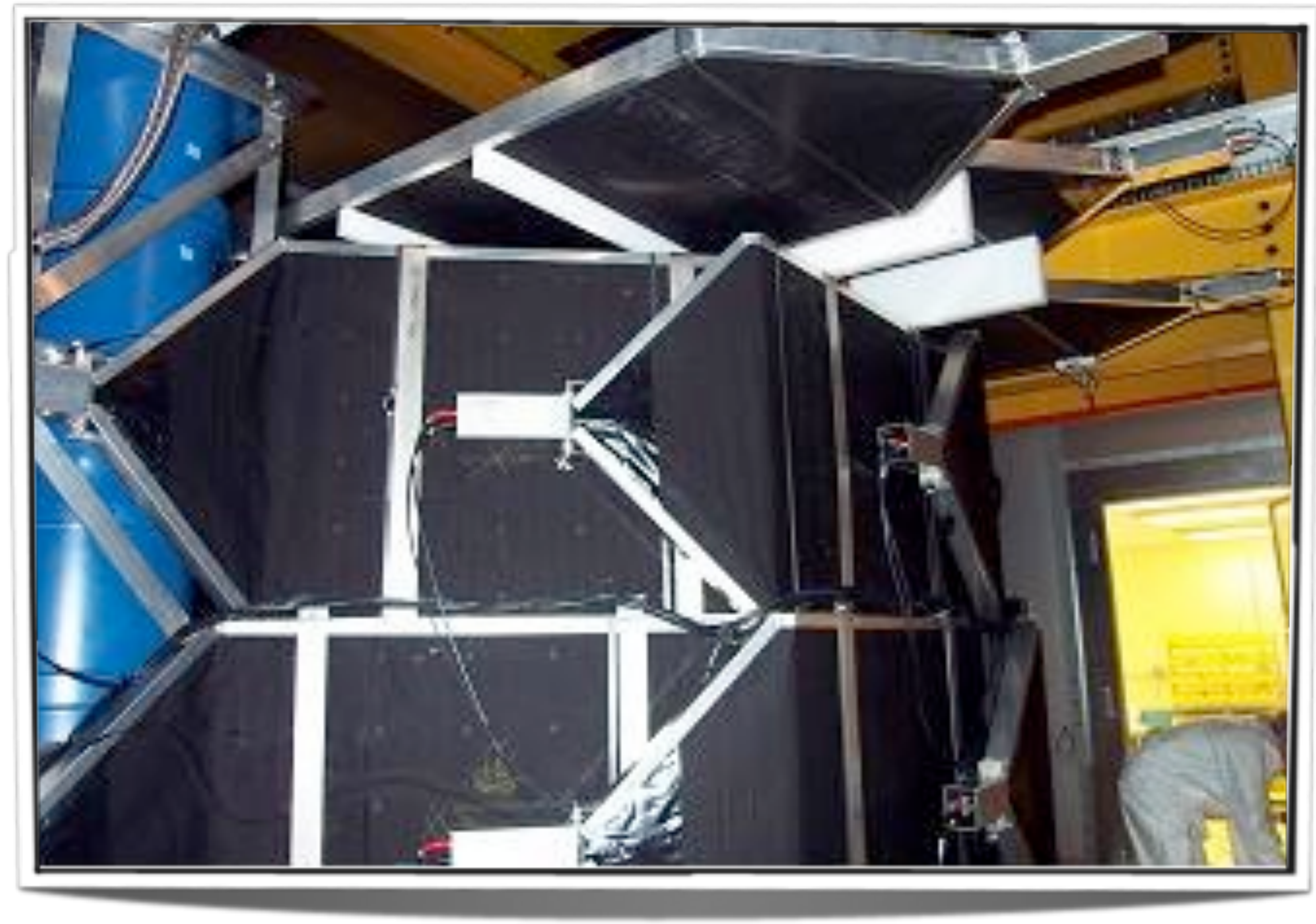
Active Muon Veto:

rejects events from cosmic rays

- Scintillating panels
- Water/Liquid Scintillator Shield



SABRE LAB shield design



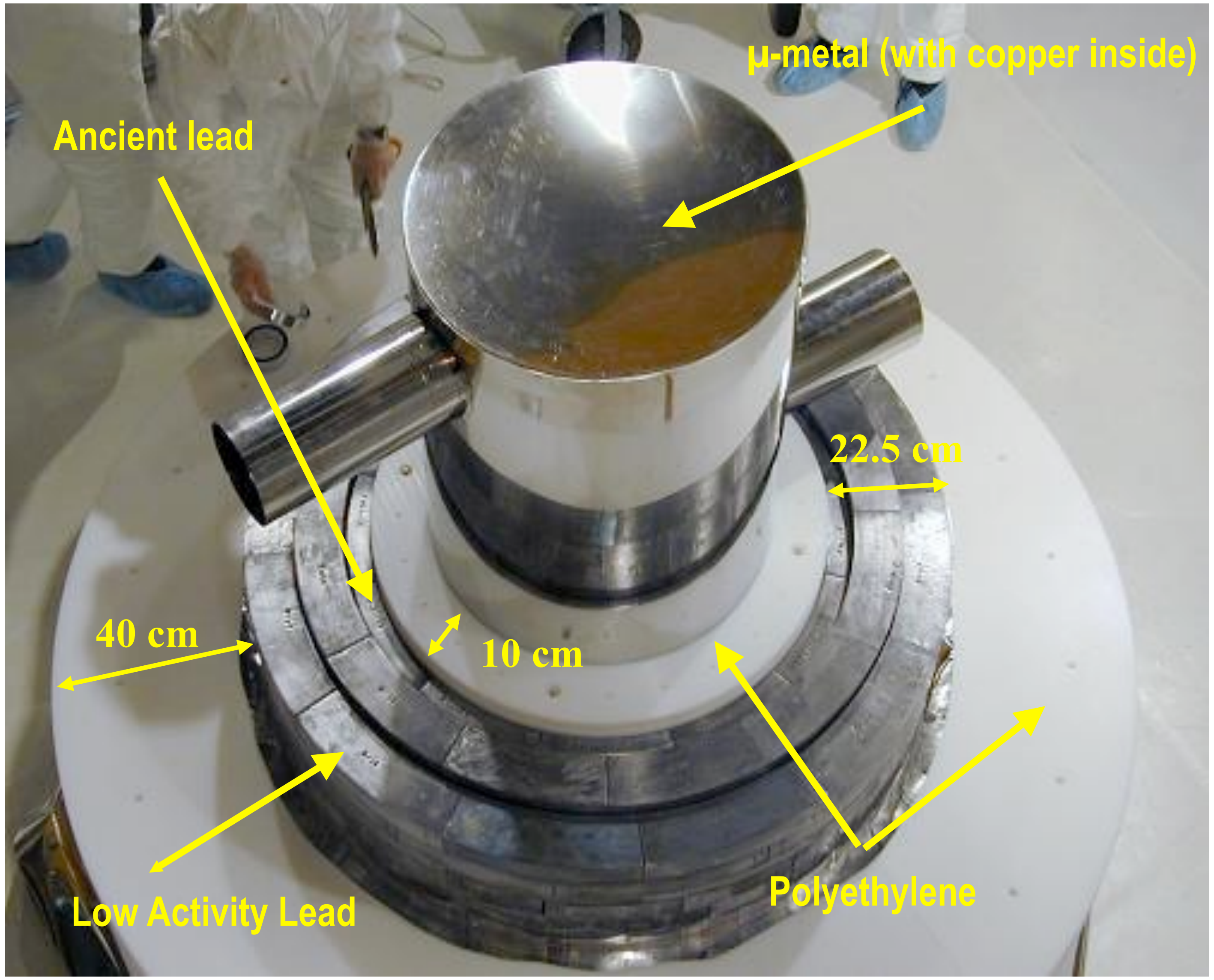
SCDMS active muon veto

Minimize Backgrounds

Use Passive Shielding

Pb: shielding from gammas resulting from radioactivity

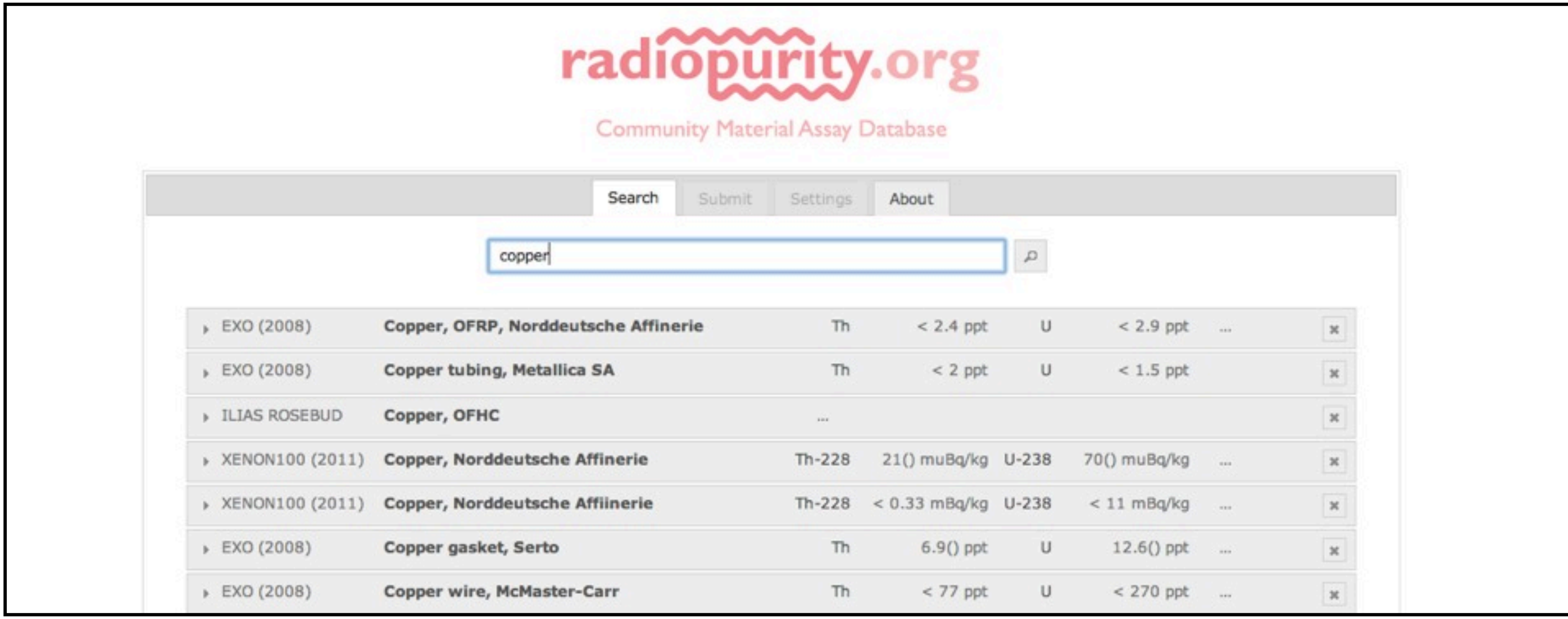
Polyethyene: moderate neutrons produced from fission decays and from (α,n) interactions resulting from U/Th decays



SCDMS - Layers of Polyethylene and Lead

Minimize Backgrounds

Use Clean Materials



radiopurity.org

Community Material Assay Database

Search | Submit | Settings | About

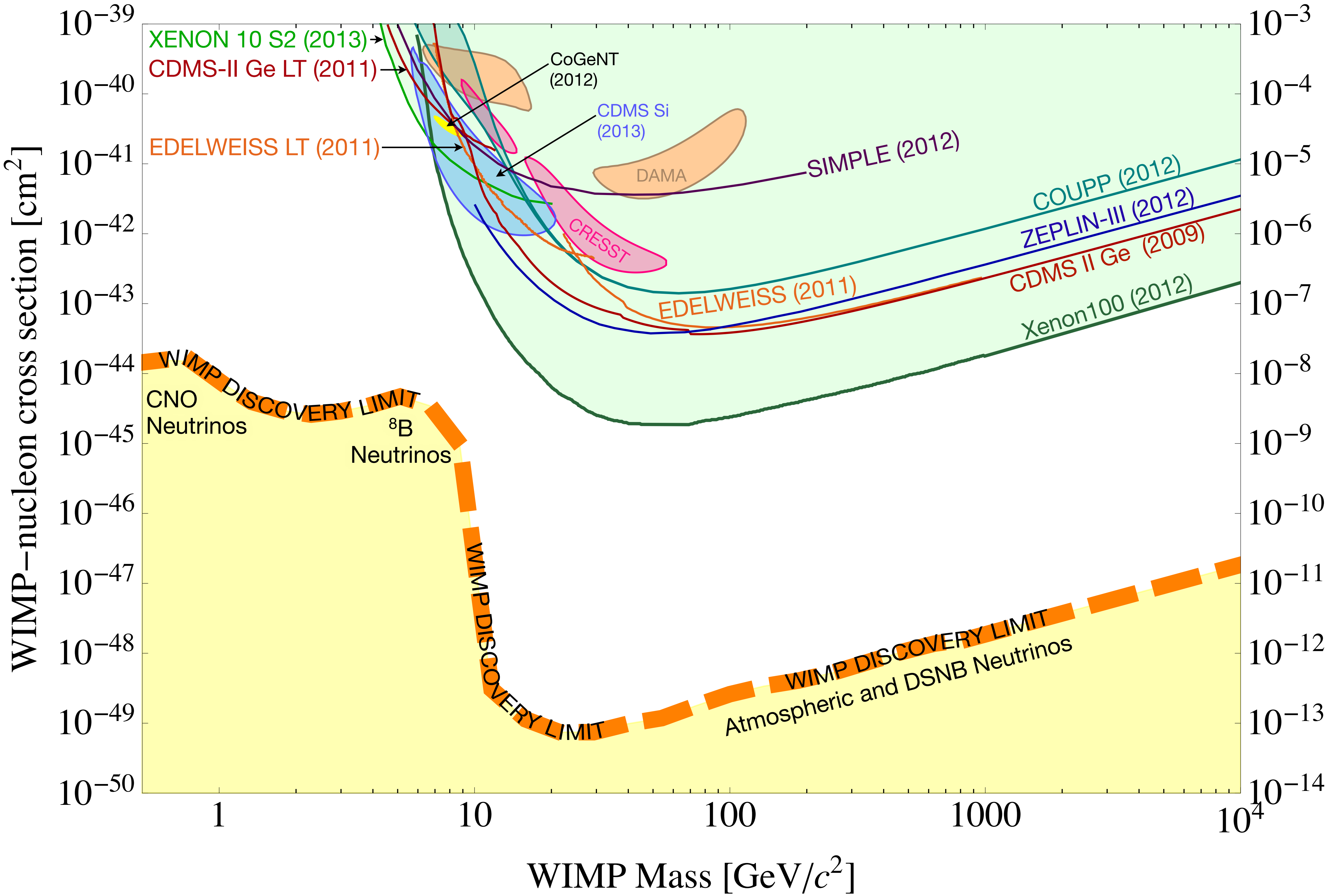
copper

EXO (2008)	Copper, OFRP, Norddeutsche Affinerie	Th	< 2.4 ppt	U	< 2.9 ppt	...
EXO (2008)	Copper tubing, Metallica SA	Th	< 2 ppt	U	< 1.5 ppt	
ILIAS ROSEBUD	Copper, OFHC	...				
XENON100 (2011)	Copper, Norddeutsche Affinerie	Th-228	21() muBq/kg	U-238	70() muBq/kg	...
XENON100 (2011)	Copper, Norddeutsche Affiinerie	Th-228	< 0.33 mBq/kg	U-238	< 11 mBq/kg	...
EXO (2008)	Copper gasket, Serto	Th	6.9() ppt	U	12.6() ppt	...
EXO (2008)	Copper wire, McMaster-Carr	Th	< 77 ppt	U	< 270 ppt	...

http://radiopurity.org

Supported by AARM, LBNL, MAJORANA, SMU, SJTU & others

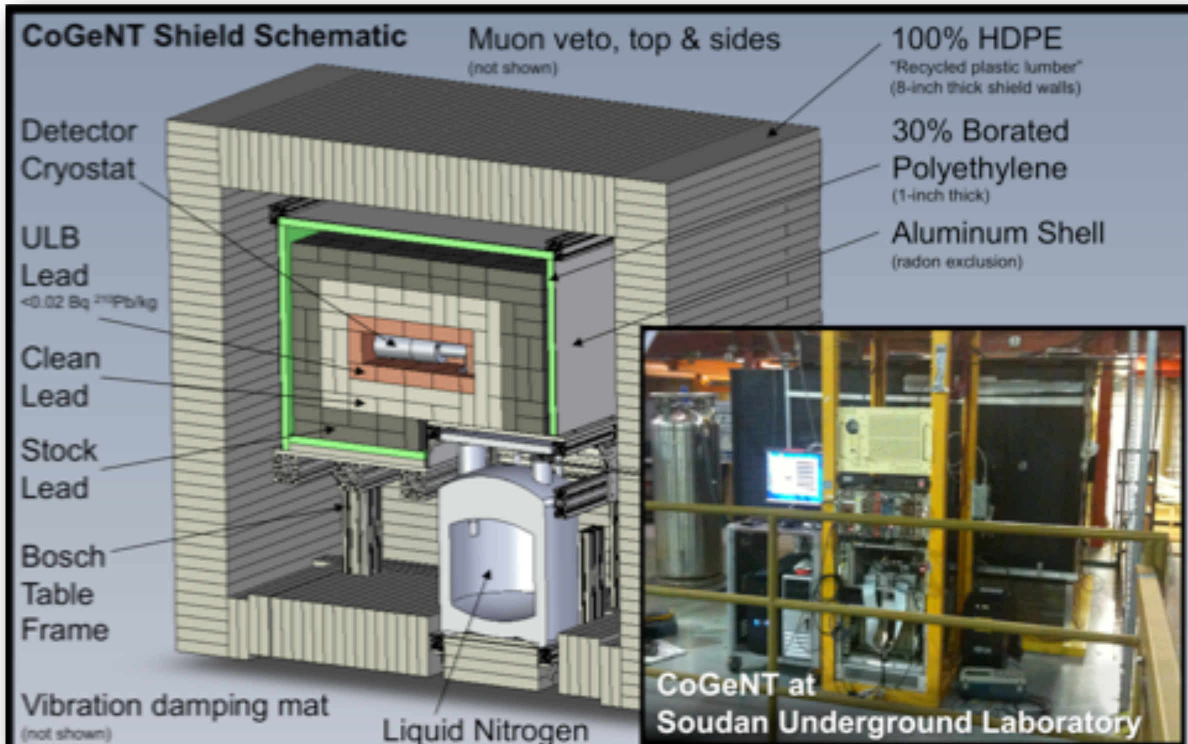
Where Are We Now?

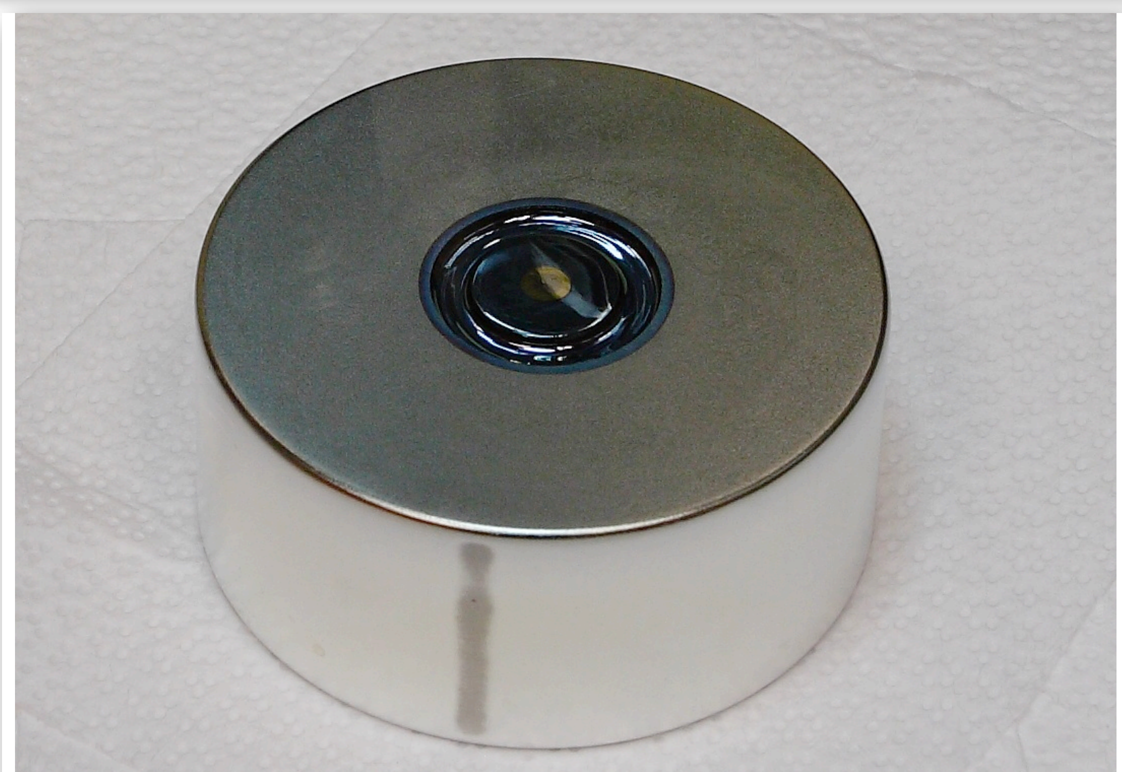


The Experiments Part 1: The Low Mass Region

Excesses Reported by DAMA/LIBRA, CoGeNT, CRESST and CDMS

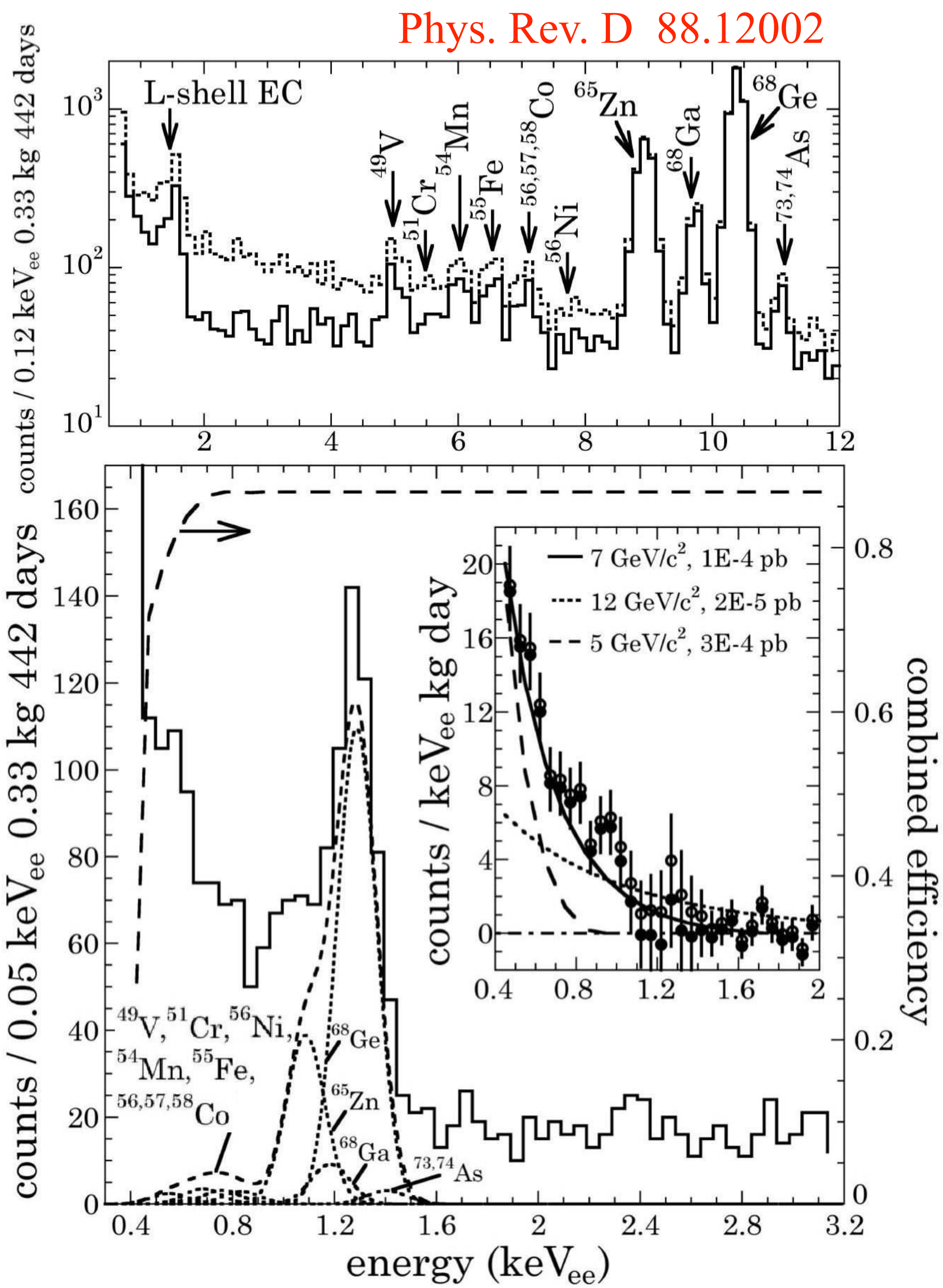
CoGeNT





- Location: Soudan Underground Laboratory, Minnesota, USA
- 440 g HPGe ionization spectrometer
- Data collection from Dec. 4, 2009 - Mar. 6, 2011 (442 live days)
- Data collection interrupted due to fire.
- Data collection resumed July 2011.

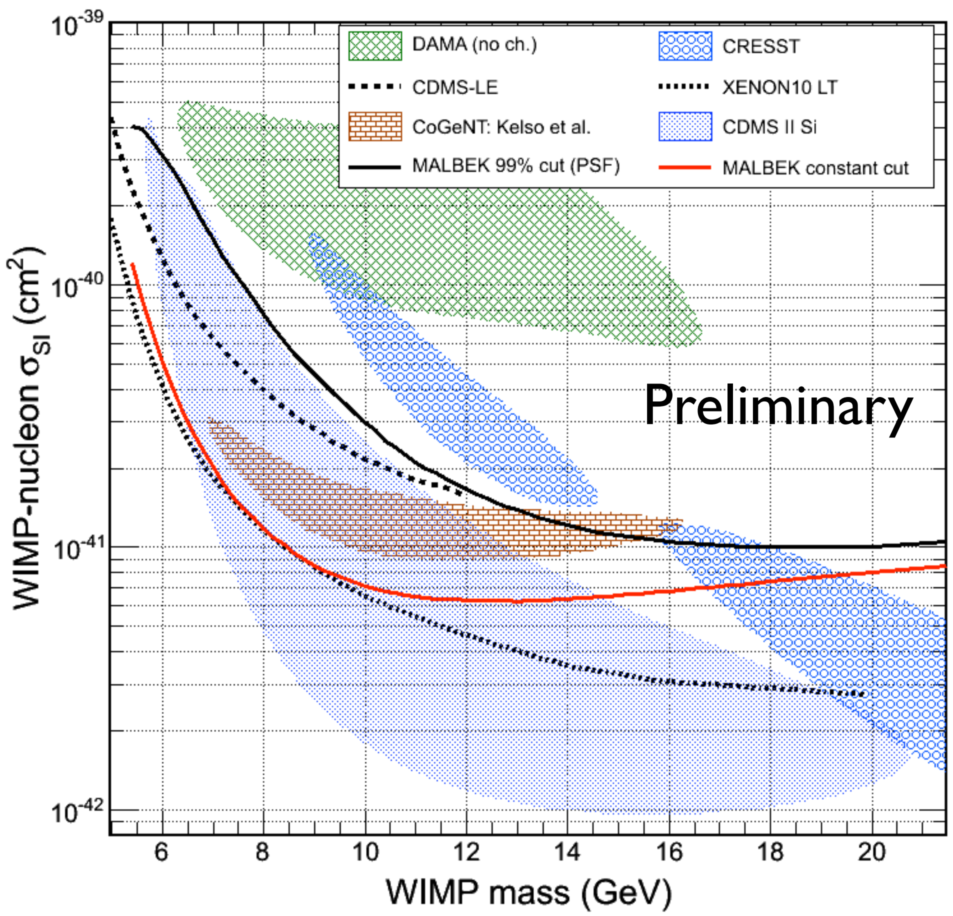
CoGeNT

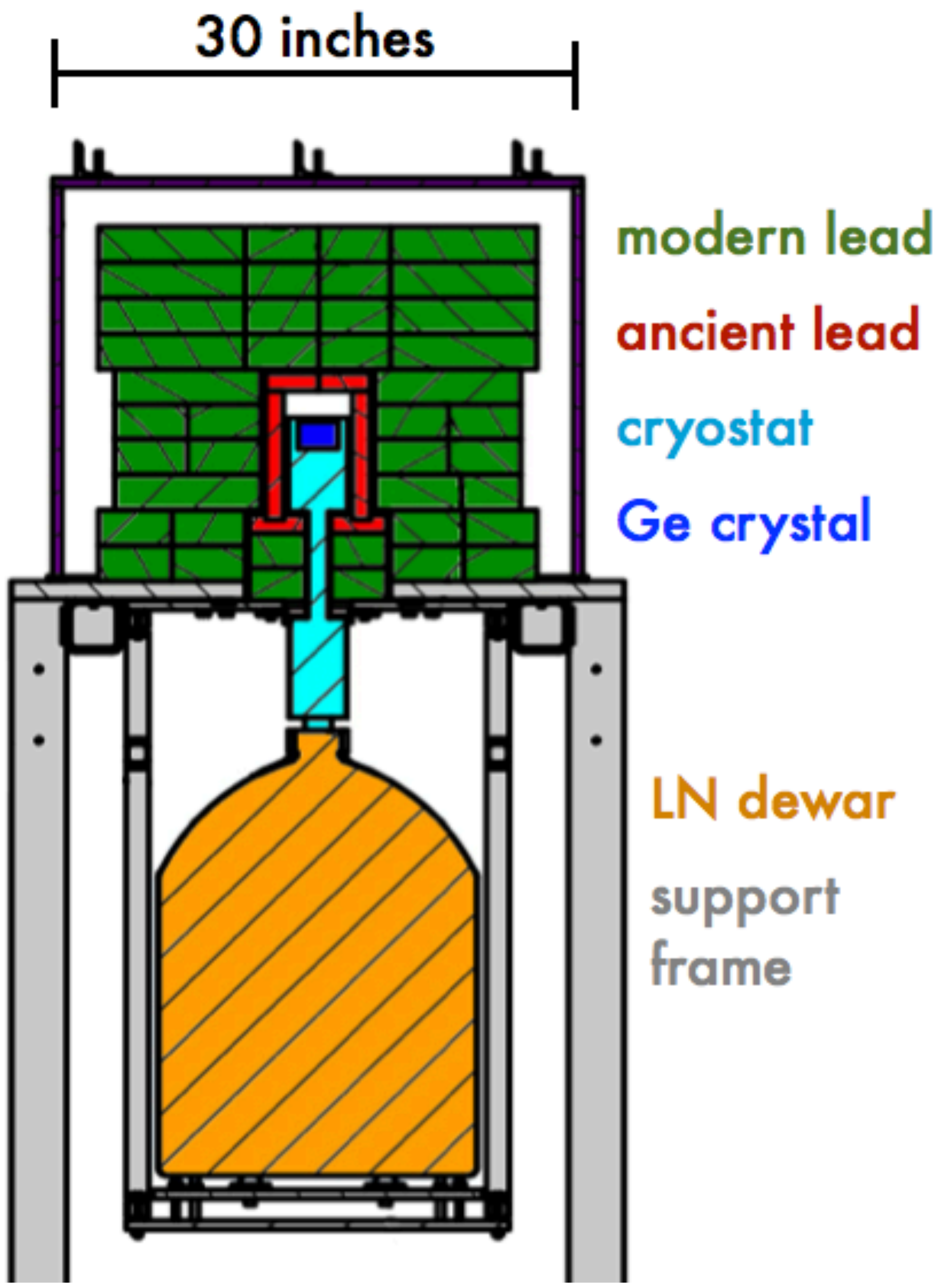


- First claim of excess in 2010.
- Reject surface events using risetime cut (2011).
- Peaks due to cosmogenic activation of Ge
- After subtraction of known background, an exponential excess of events remains
- Fits to a variety of light-WIMP masses and couplings shown in inset of lower figure.
- Publication of new data coming soon.

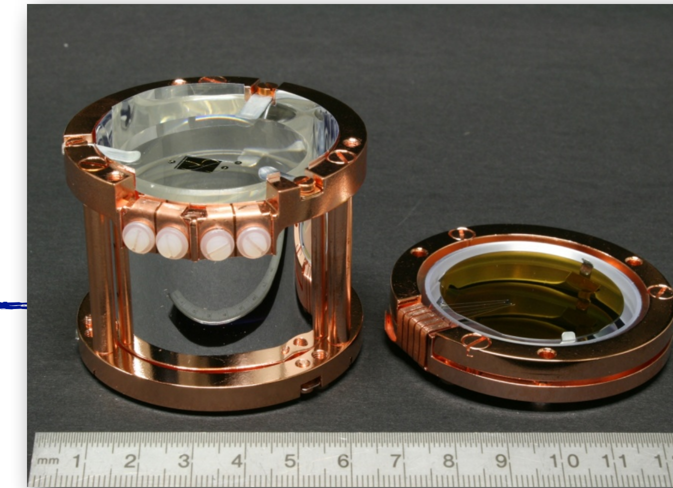
MALBEK

- MAJORANA Low-background BEGe detector at KURF.
- 450g Canberra Broad Energy Ge (BEGe) detector with ultra-low background components provided by J.I. Collar.
- Location: Kimballton Underground Research Facility (KURF), VA at 1450 mwe.
- 90% exclusion limits from 221 day data run.

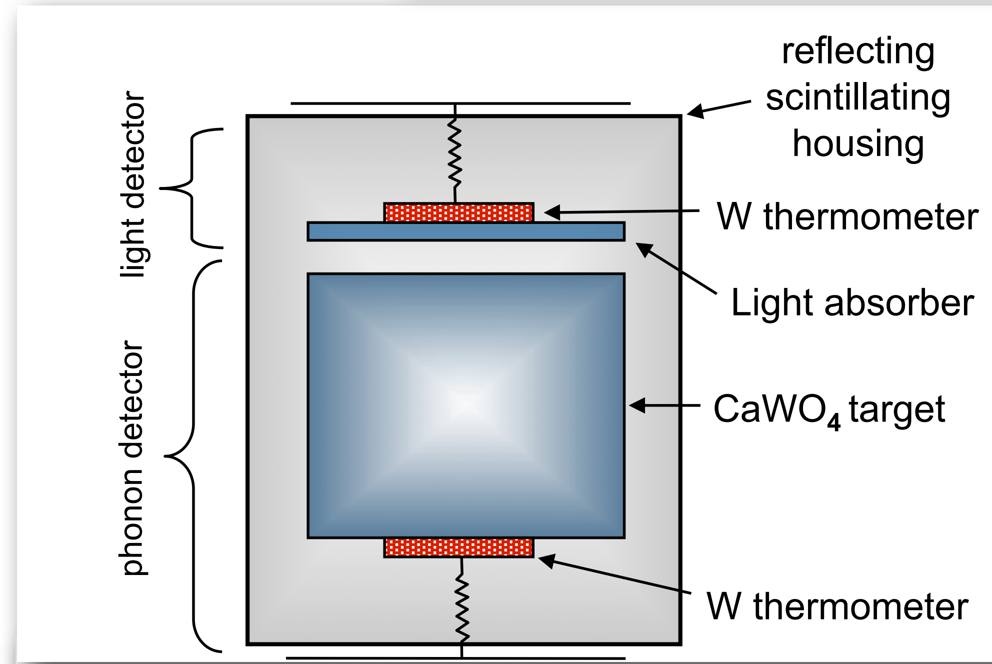


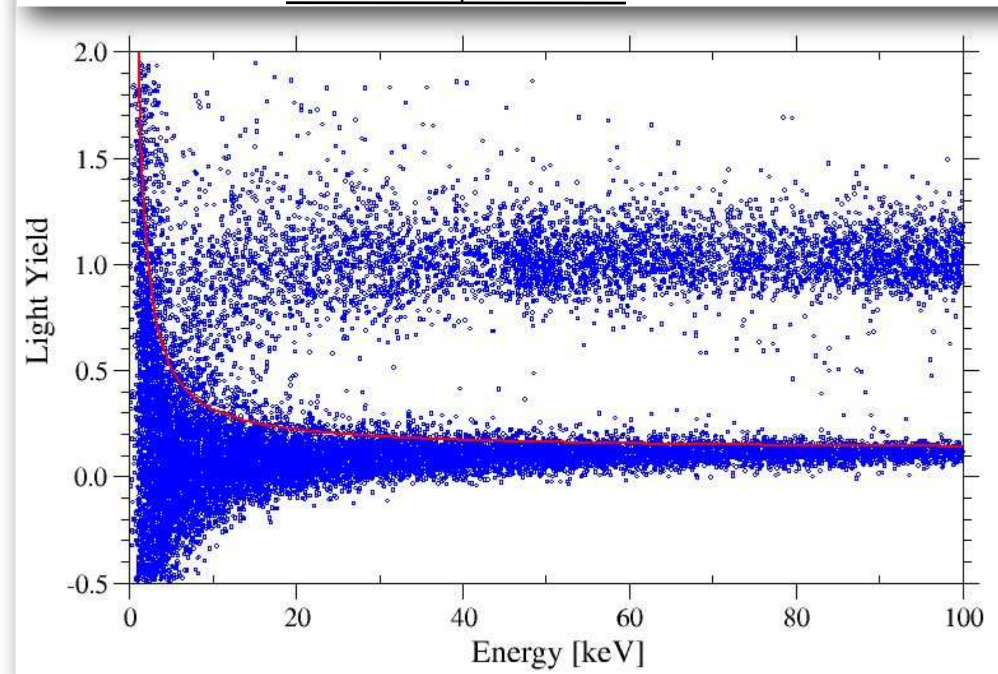


CRESST



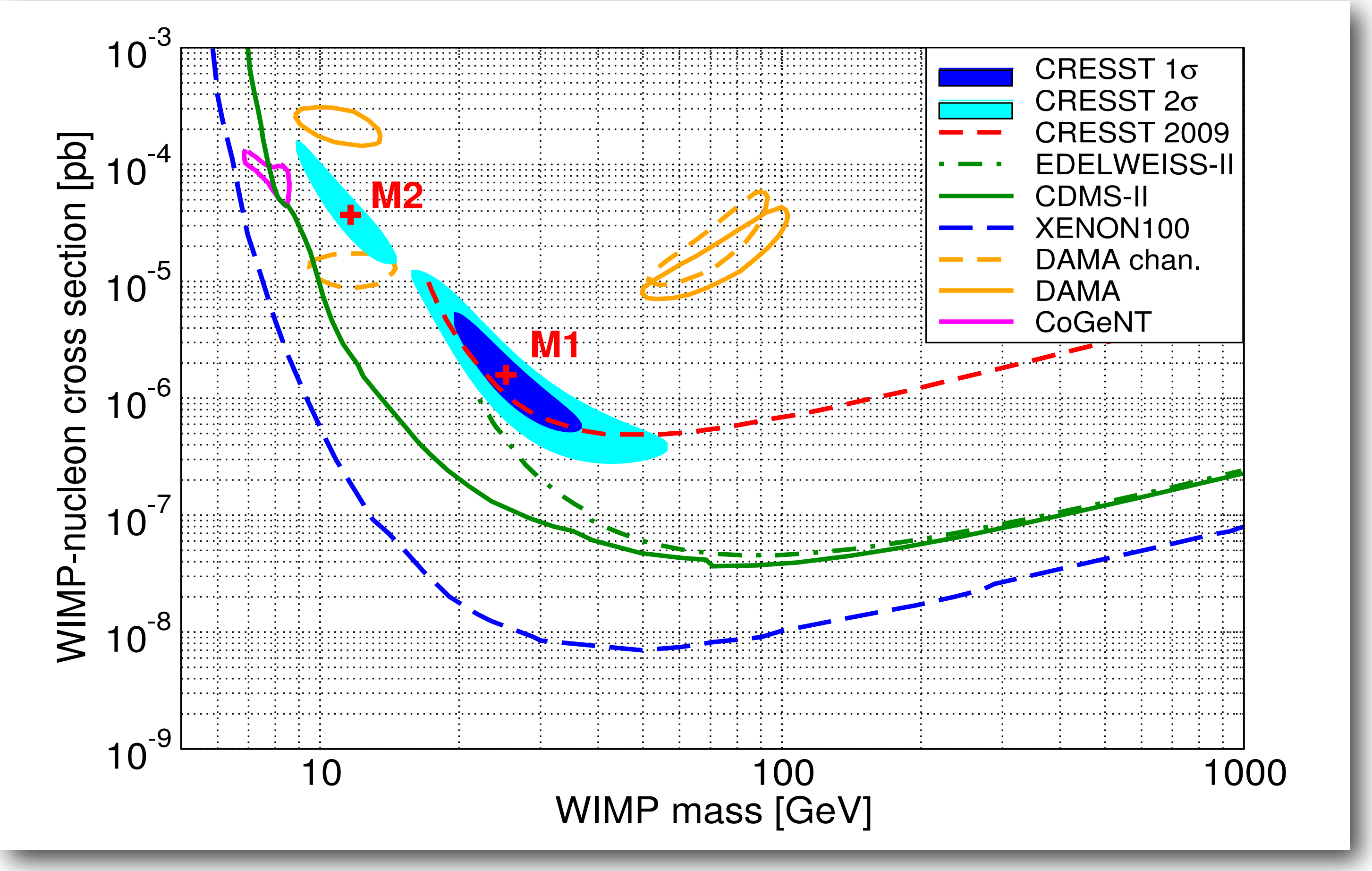
- Cryogenic $CaWO_4$ crystals (~300 g each) are instrumented to readout phonon energy and scintillation.
- Location: Laboratori Nazionali del Gran Sasso, Italy
- Discrimination between ER and NR events via light yield (light/phonon energy)
- Net exposure: 730 kg-day (July 2009 - March 2011) from 8 detector modules.
- Observed 67 events in acceptance region (orange). **arXiv:1109.0702**
  - Analysis used a maximum likelihood in which 2 regions favored a WIMP signal in addition to predict background.
  - Excess events can not be explained by known backgrounds
  - Large background contribution





CRESST Plans

- Current data run aims to reduce background, increase detector mass.
  - Alphas - new clamping design and material
  - Detector assembly in a radon free environment
  - New detector design to discriminate ^{206}Po recoils
  - Add additional shielding to reduce neutron background

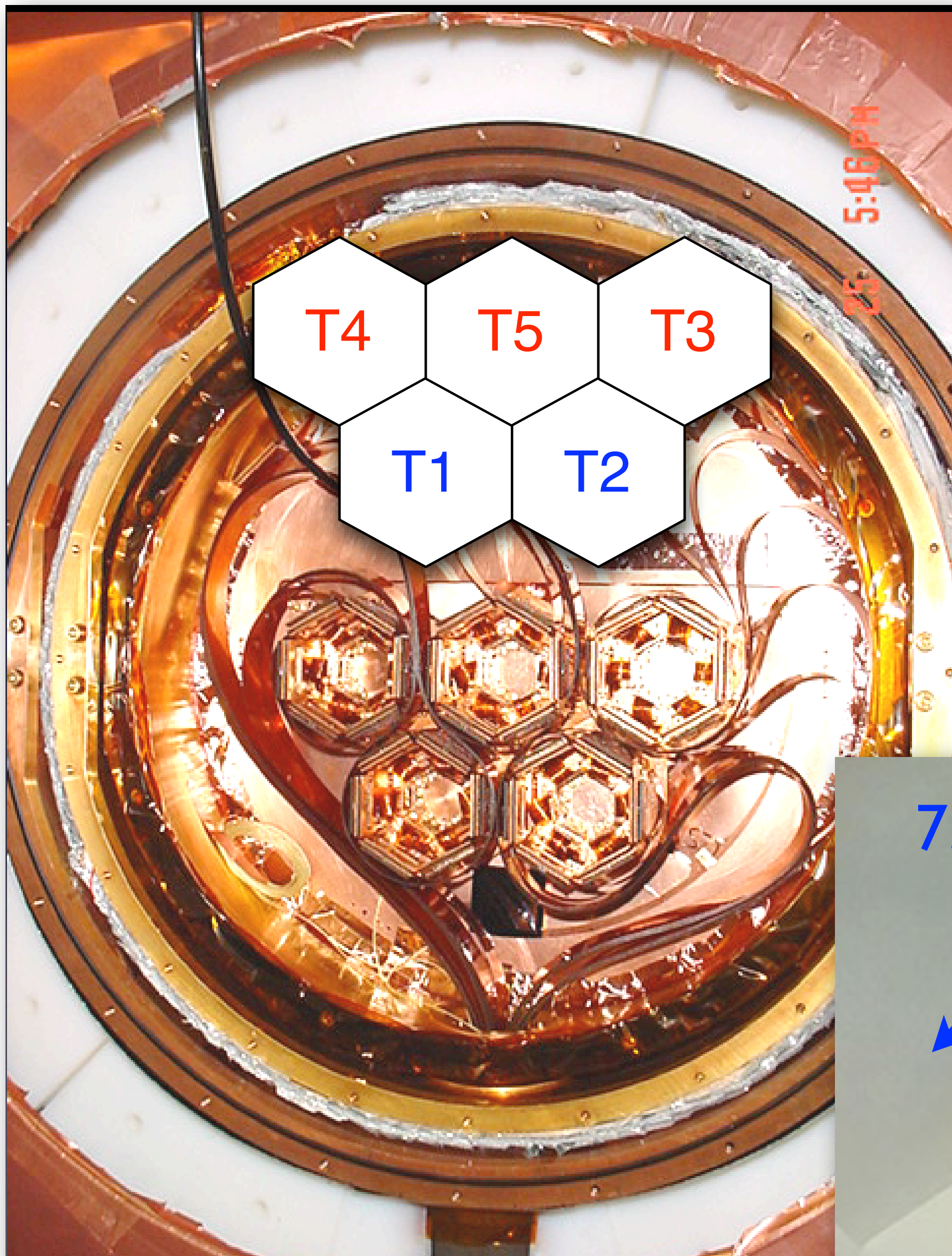


arXiv:1109.0702

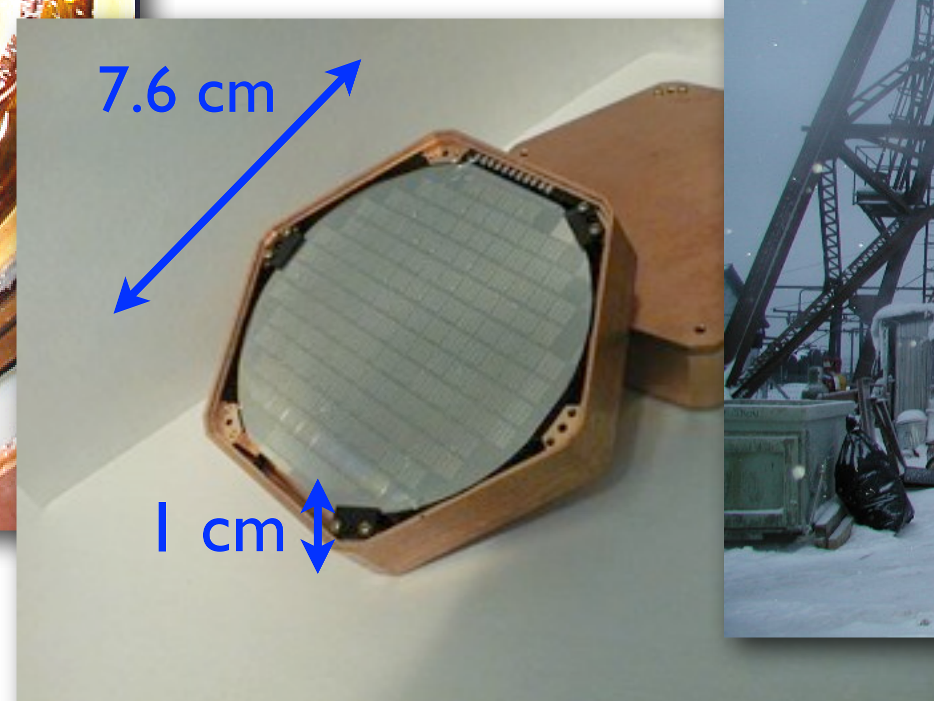
- June & July calibration runs with ^{57}Co source were successful.
- **July 30th, 2013 Science Runs Begin!**

CDMS II

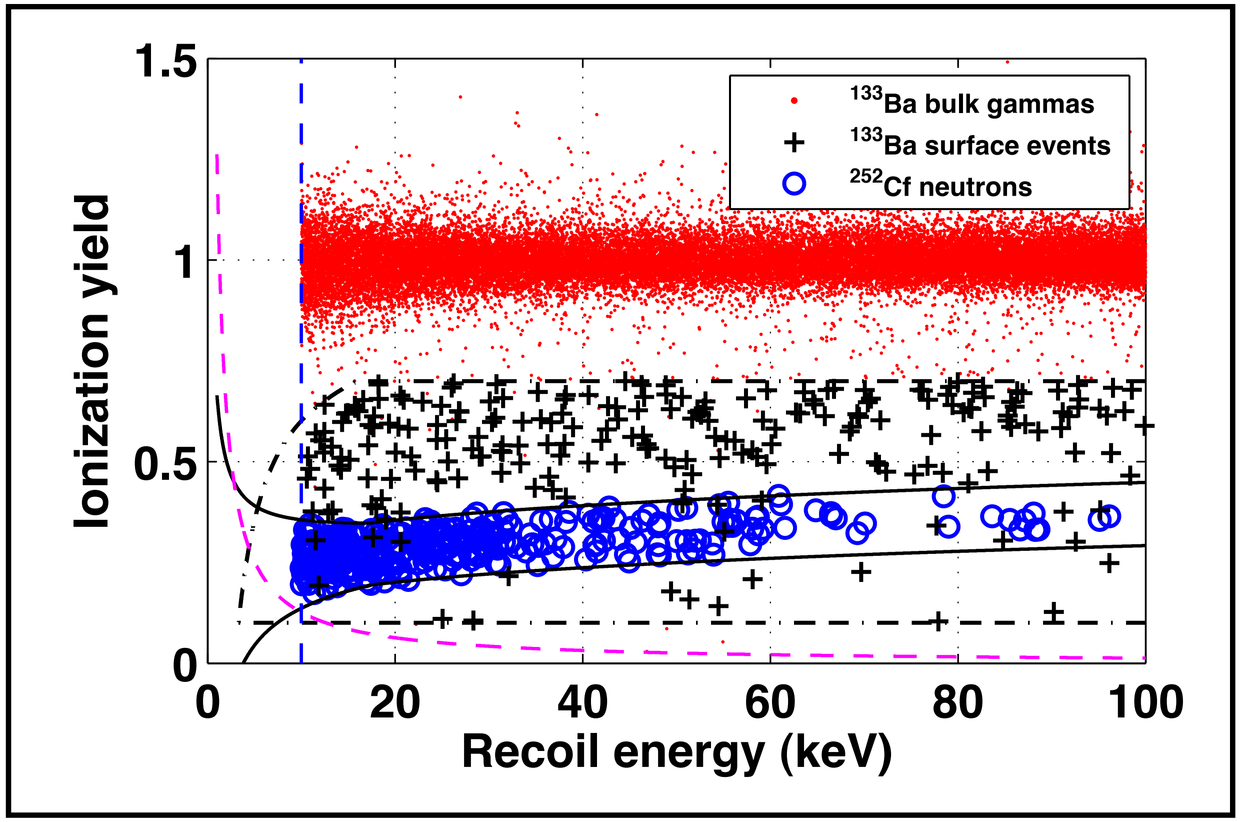
Billard - Mon. DM I
Nelson - Mon. DM II
Speller - Poster

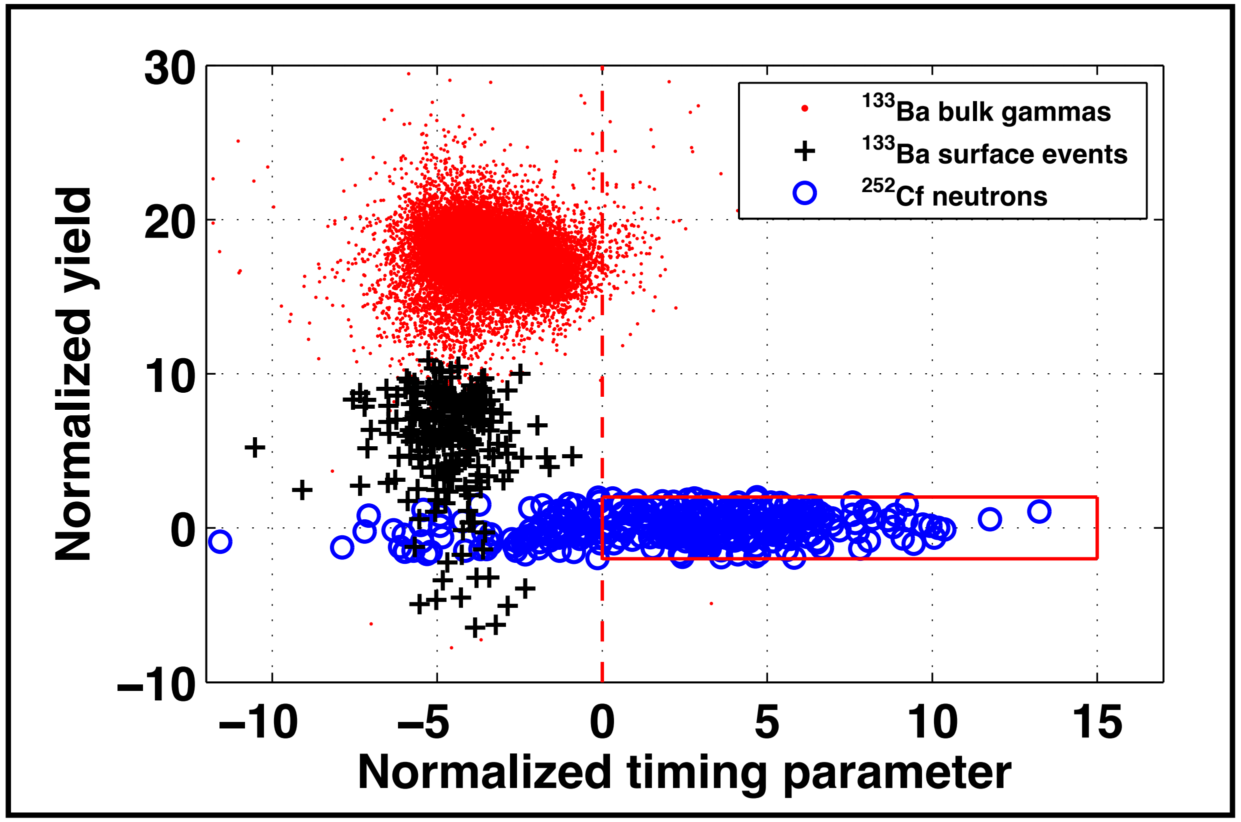


- CDMS II: 30 detectors (19 Ge, 11 Si) installed and operated in the Soudan Underground Laboratory, MN, USA from Jun. 06 - Mar. 09.
- Measures ionization and phonons (read out by TES)
- Science Results: CDMS-Ge, CDMS-Si, Ge-Low Threshold, Annual Modulation



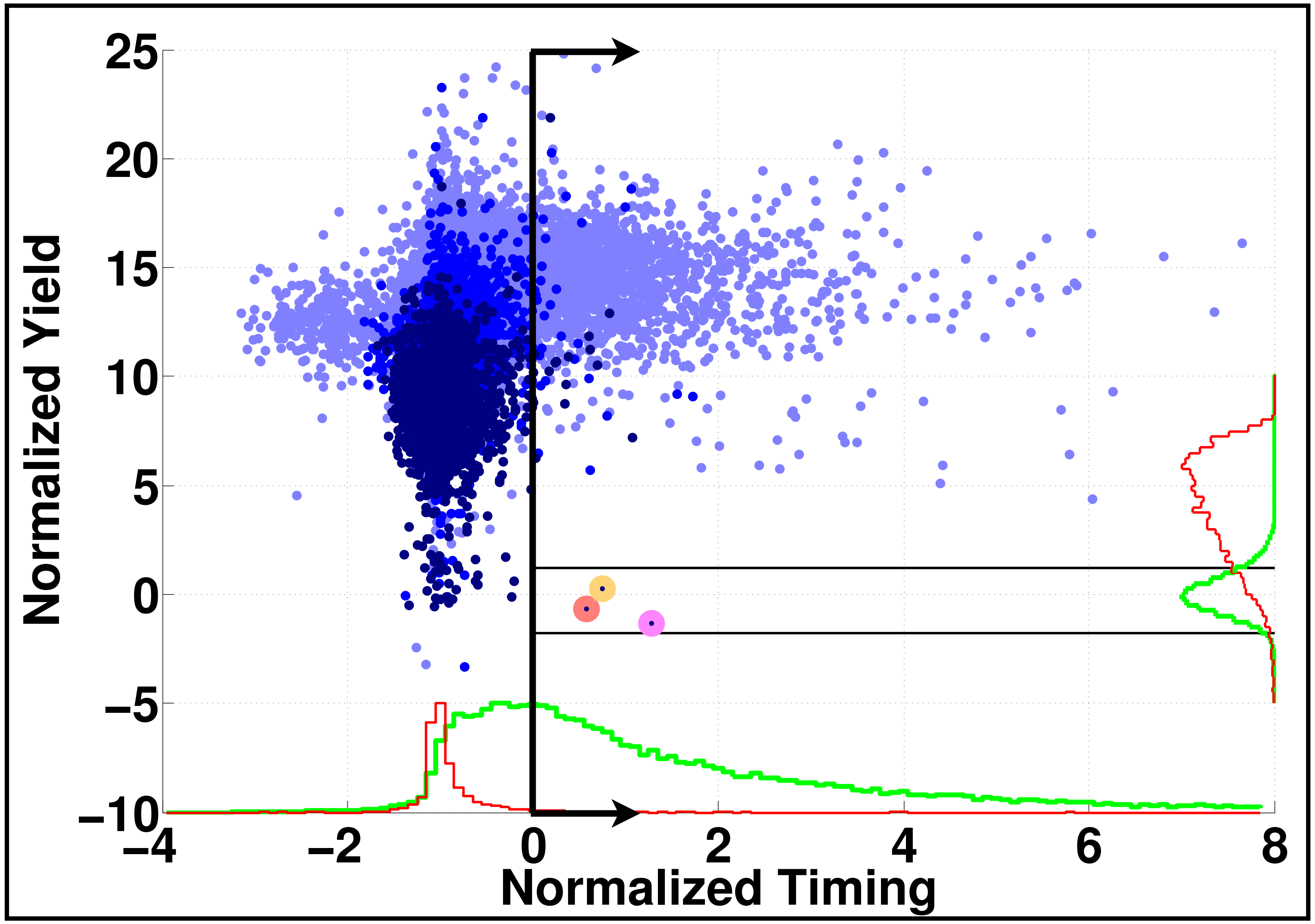
Background Rejection





- Most backgrounds produce electron recoils and have yield (ionization/phonon energy) ~1.
- WIMPs and neutrons produce nuclear recoils and have yield ~0.3.
- Surface events can be identified using timing properties of the phonon and charge pulses.

Recent Results: CDMS II-Si Detectors

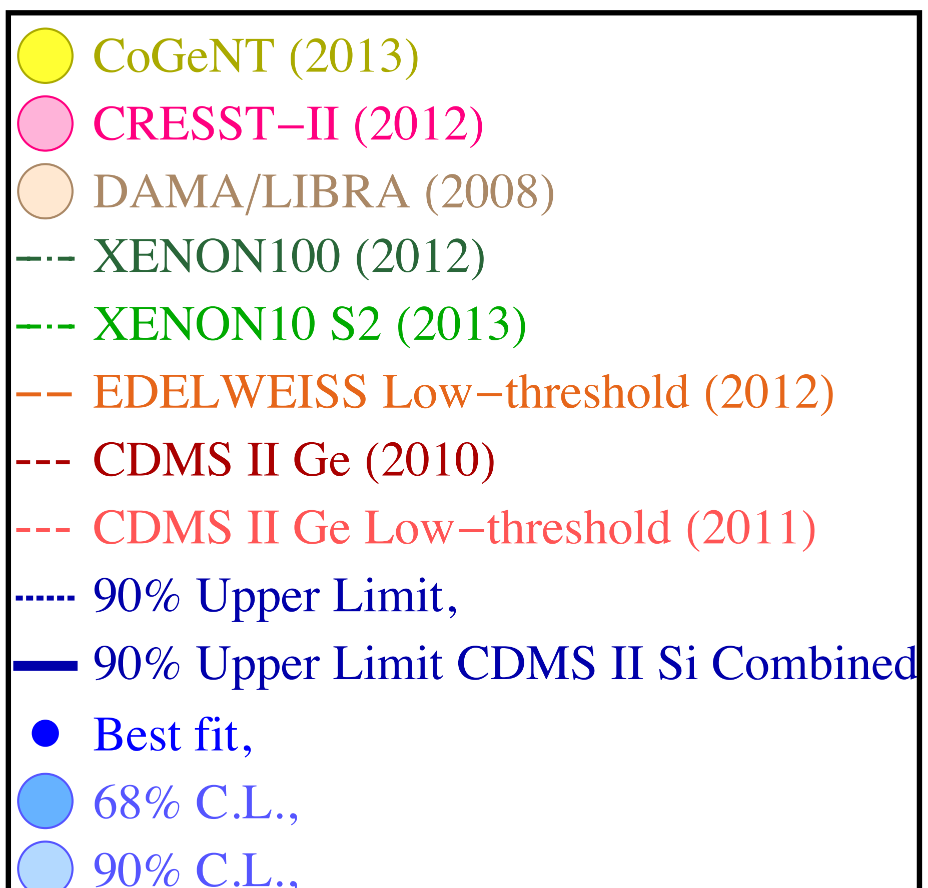


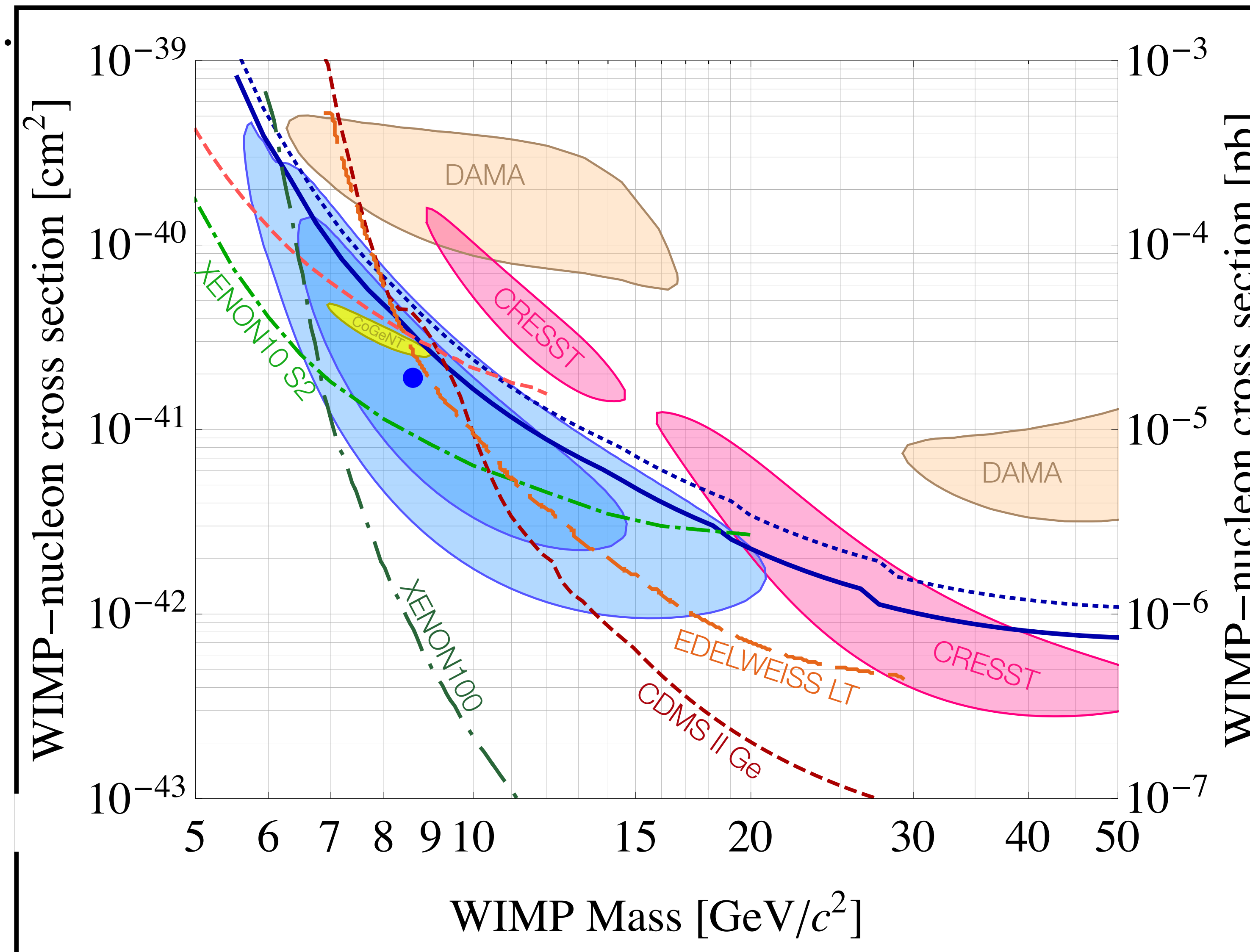
Observed 3 events.

- Shades of blue indicate three separate timing cut energy ranges.
  - 7- 20 keV
  - 20 - 30 keV
  - 30 - 100 keV
- Background Estimate
  - Surface Events $0.41^{+0.20}_{-0.08}(stat.)^{+0.28}_{-0.24}(syst.)$
  - < 0.13 neutrons from Cosmogenics & Radiogenics
  - < 0.08 ^{206}Pb recoils from ^{210}Pb decays

CDMS II - Si Results

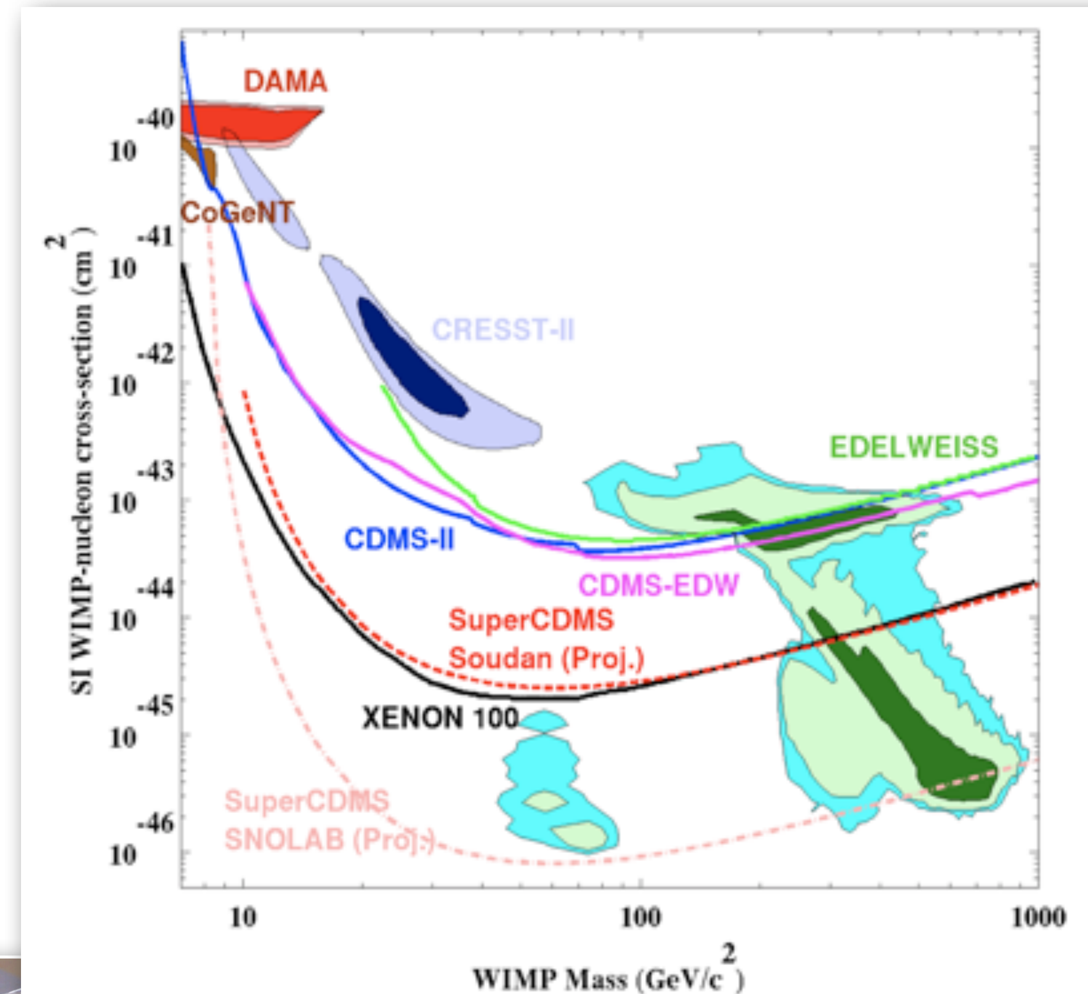
- Three events observed in the signal region.
- A profile likelihood analysis favors a WIMP+background hypothesis over the known background estimate as the source of our signal at the 99.81% C.L. (~3σ, p-value: 0.19%)
- The maximum likelihood occurs at a WIMP mass of 8.6 GeV/c^2 and WIMP-nucleon cross section of 1.9 x 10^{-41}.
- Does not rise to level of discovery, but does call for further investigation.

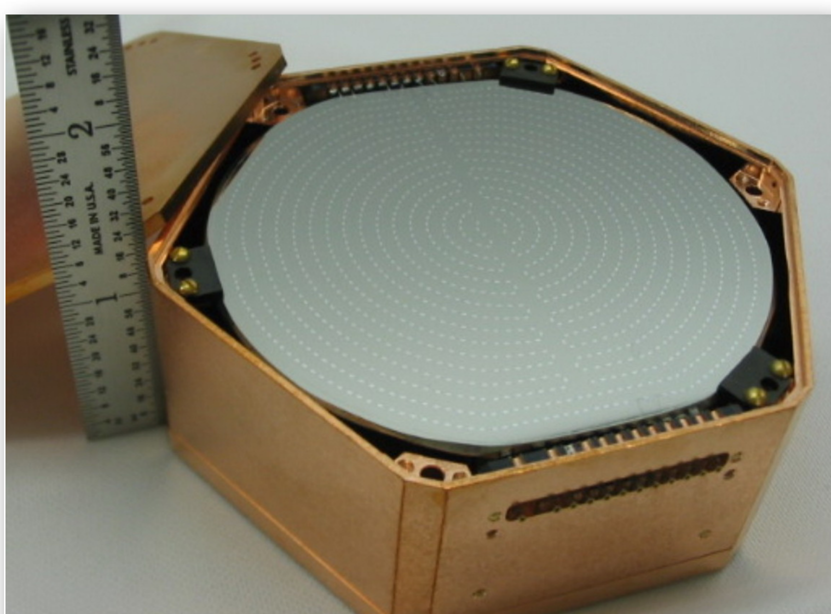


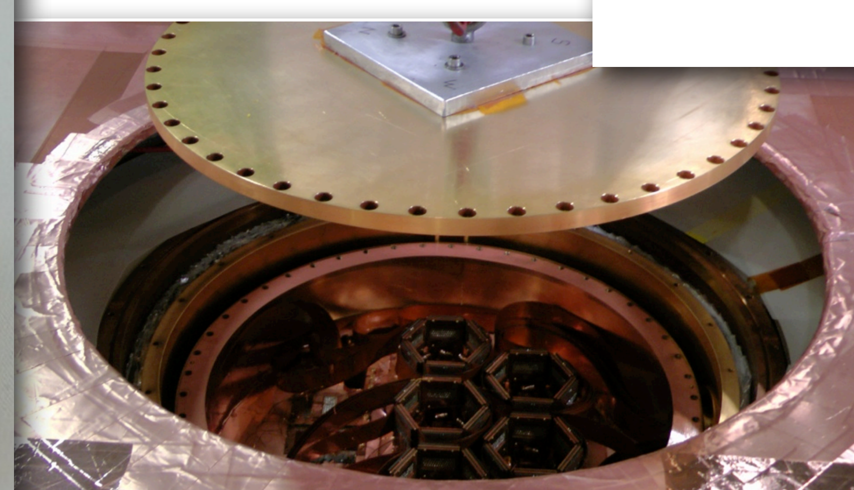


SuperCDMS @ Soudan

- Currently operating 5 towers of advanced iZIP detectors (~9 kg Ge) in the existing cryostat at the Soudan Underground Laboratory.
- After 3 years of operation, expected to improve sensitivity to spin-independent WIMP-nucleon interactions by a factor of ~10 over existing CDMS II results.





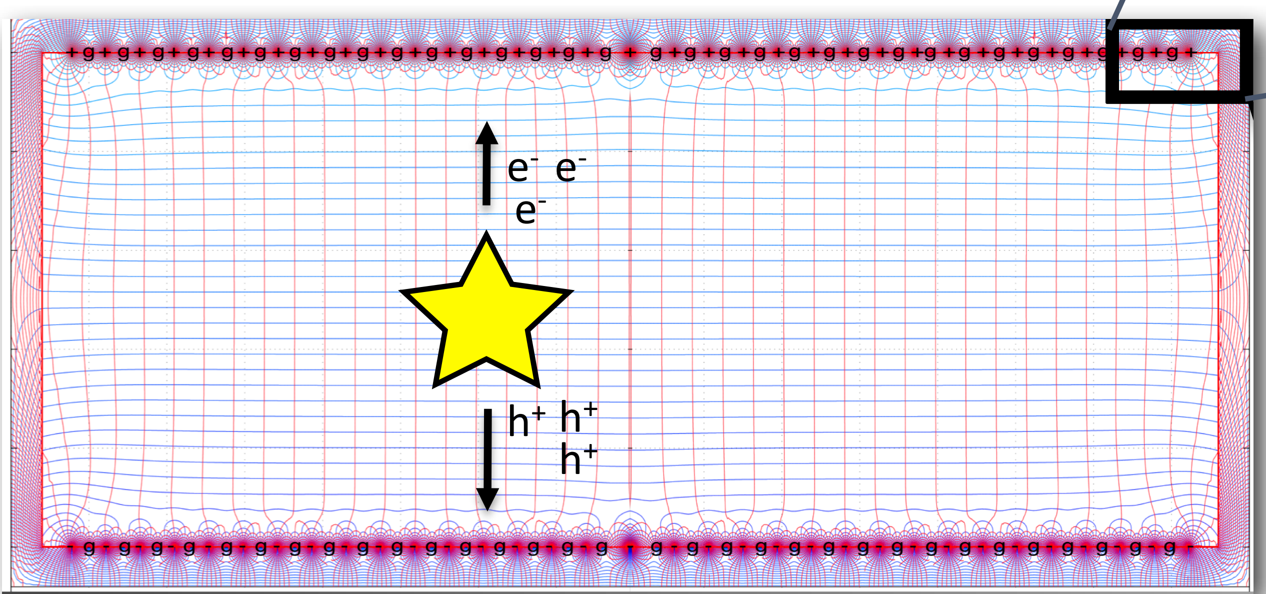


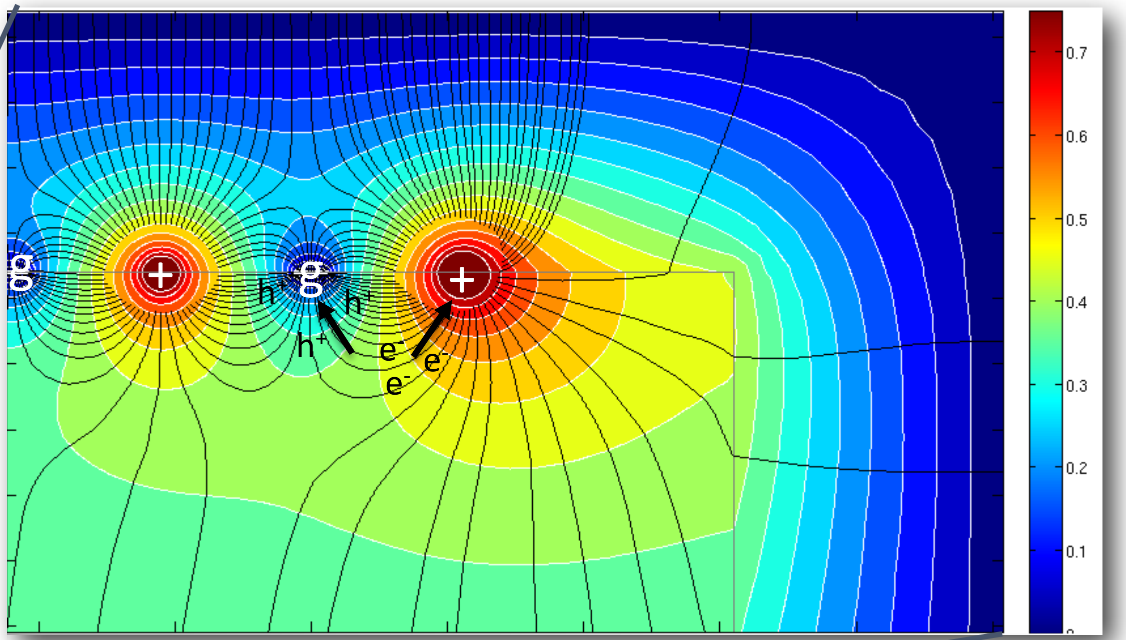
Installation complete Nov. 8, 2011. Operating with final detector settings since Mar. 2012.

SCDMS iZIPs: Charge Signal

Bulk Events:
Equal but opposite ionization signal appears on both faces of detector (symmetric)

Surface Events:
Ionization signal appears on one detector face (asymmetric)



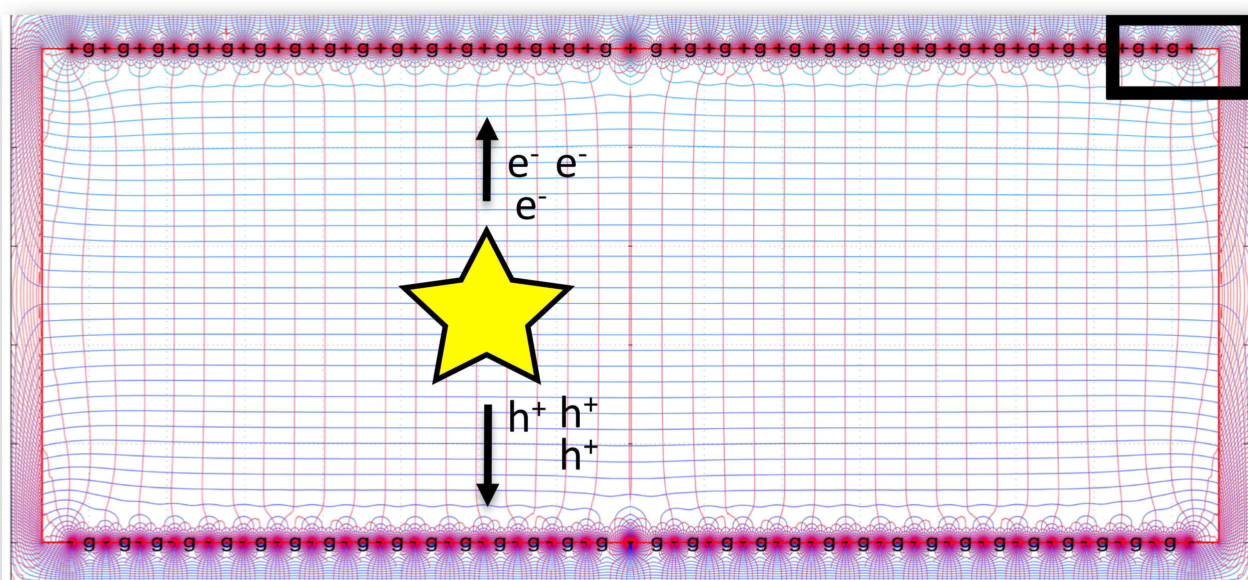


arXiv:1305.2405

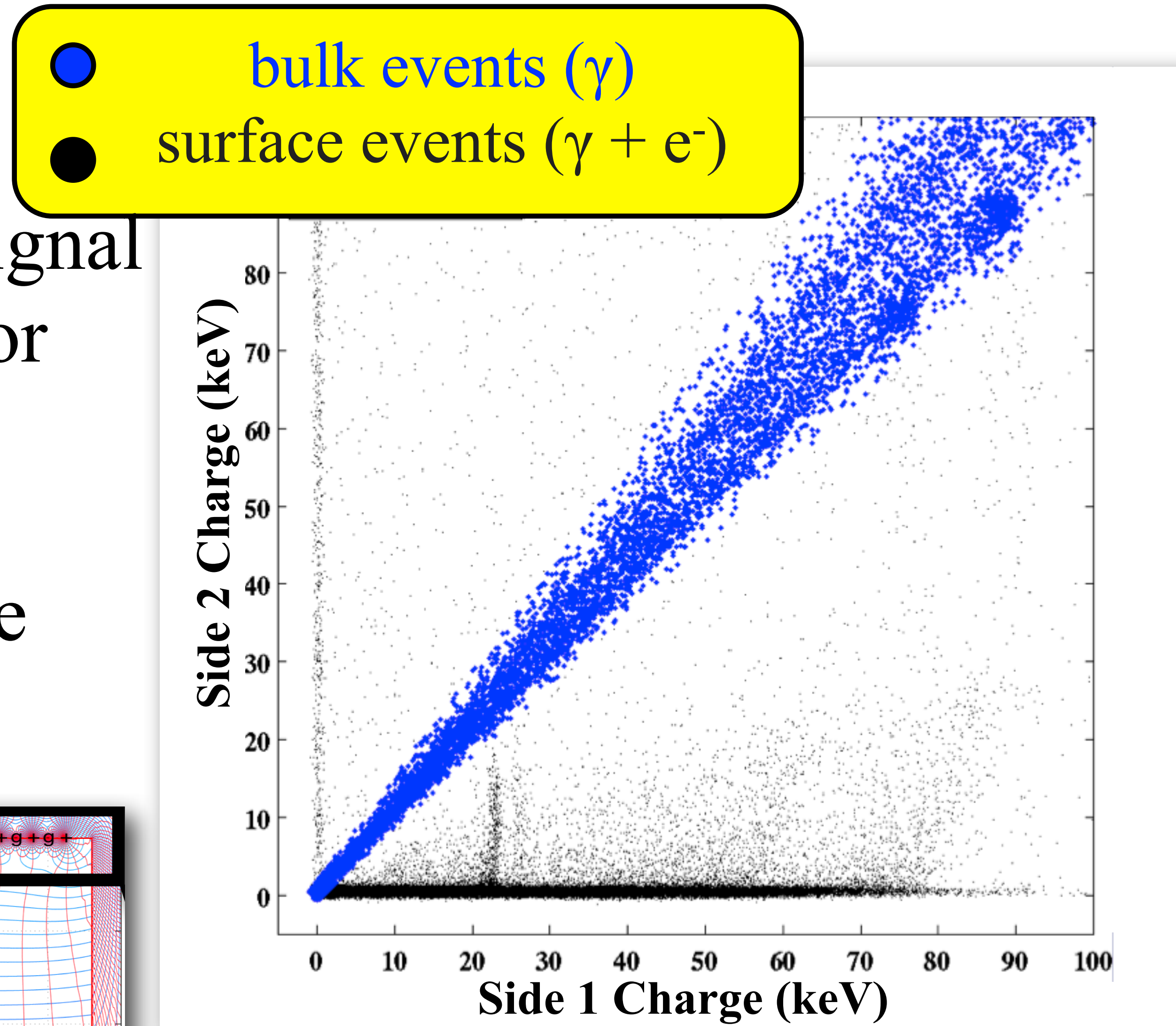
SCDMS iZIPs: Charge Signal

Bulk Events:
Equal but opposite ionization signal appears on both faces of detector (symmetric)

Surface Events:
Ionization signal appears on one detector face (asymmetric)



arXiv:1305.2405



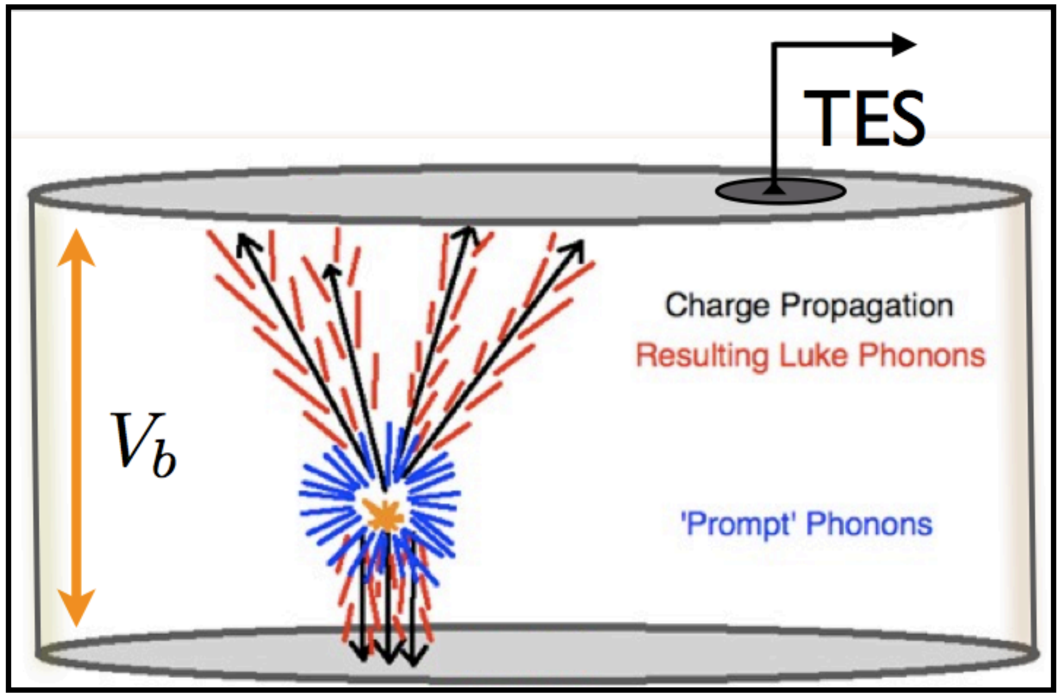
- ~50% fiducial volume (8-115 keVr)
- < 0.6 events in 0.3 ton-years
- **Good enough for a 200 kg experiment run for 4 years at SNOLAB!**

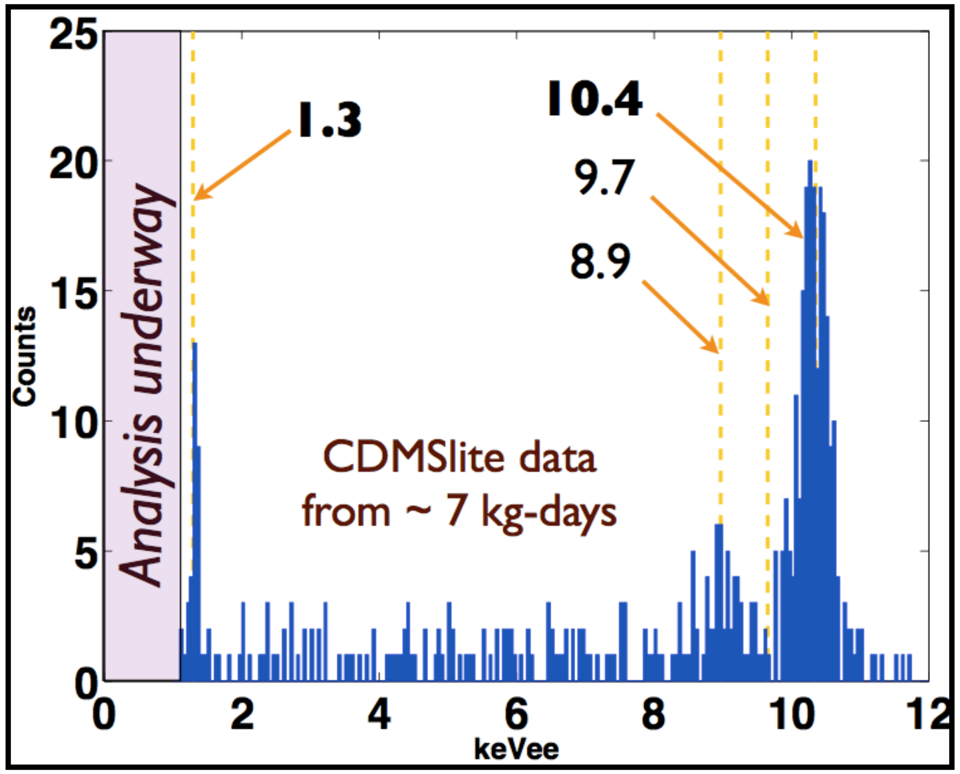
CDMSlite

- Alternate running mode to explore low mass WIMPs utilizing Luke phonons

$$E_{luke} = N_{e/h} \times eV_b$$

- Luke energy scales as bias voltage and noise remains constant until breakdown

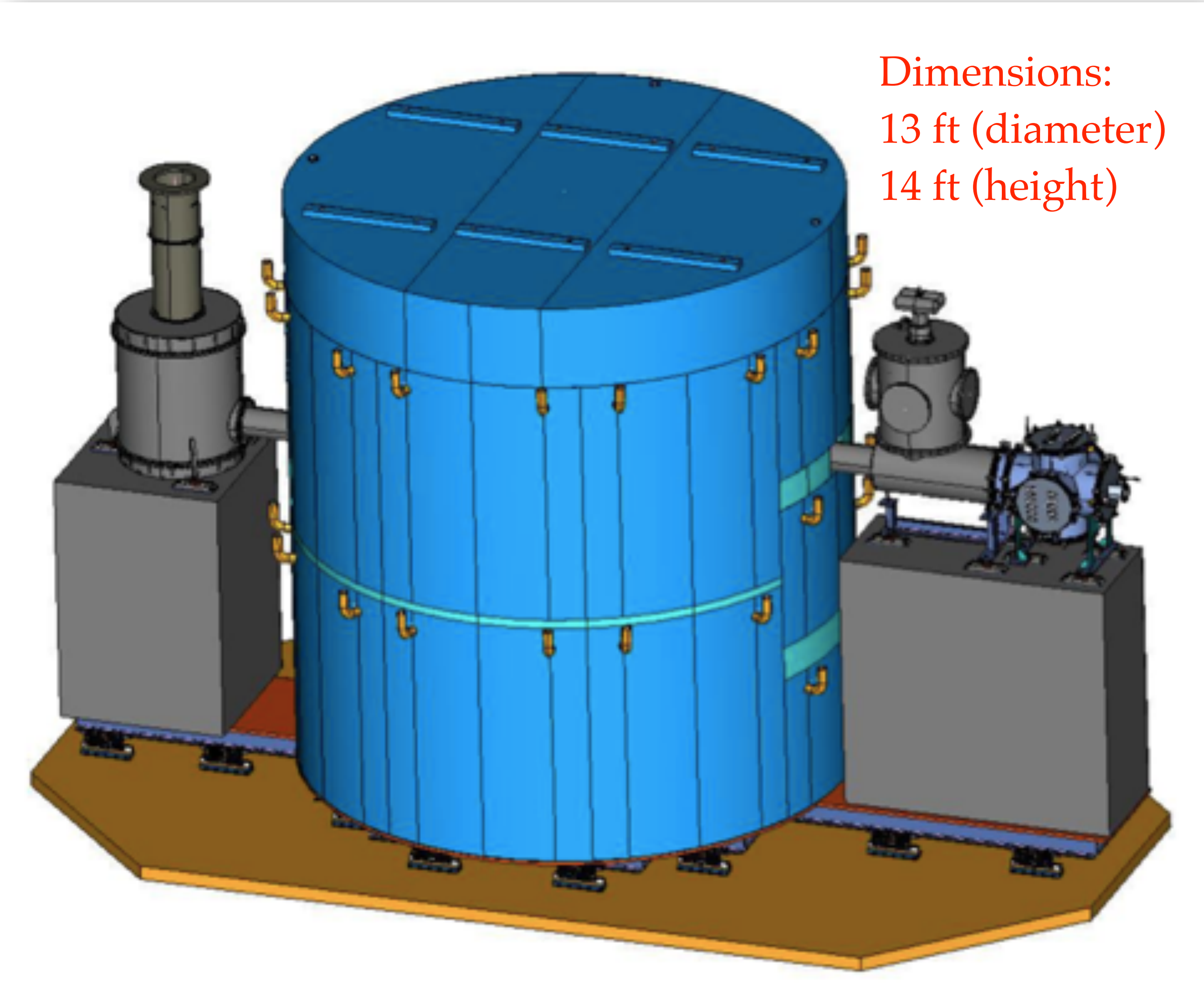




- Resulting Luke amplification has excellent energy resolution potentially down to 1.3 eeV_{ee}.
- Resolution of various Ge activation lines.

New Results to be Announced Wednesday!

Future: SuperCDMS @ SNOLAB



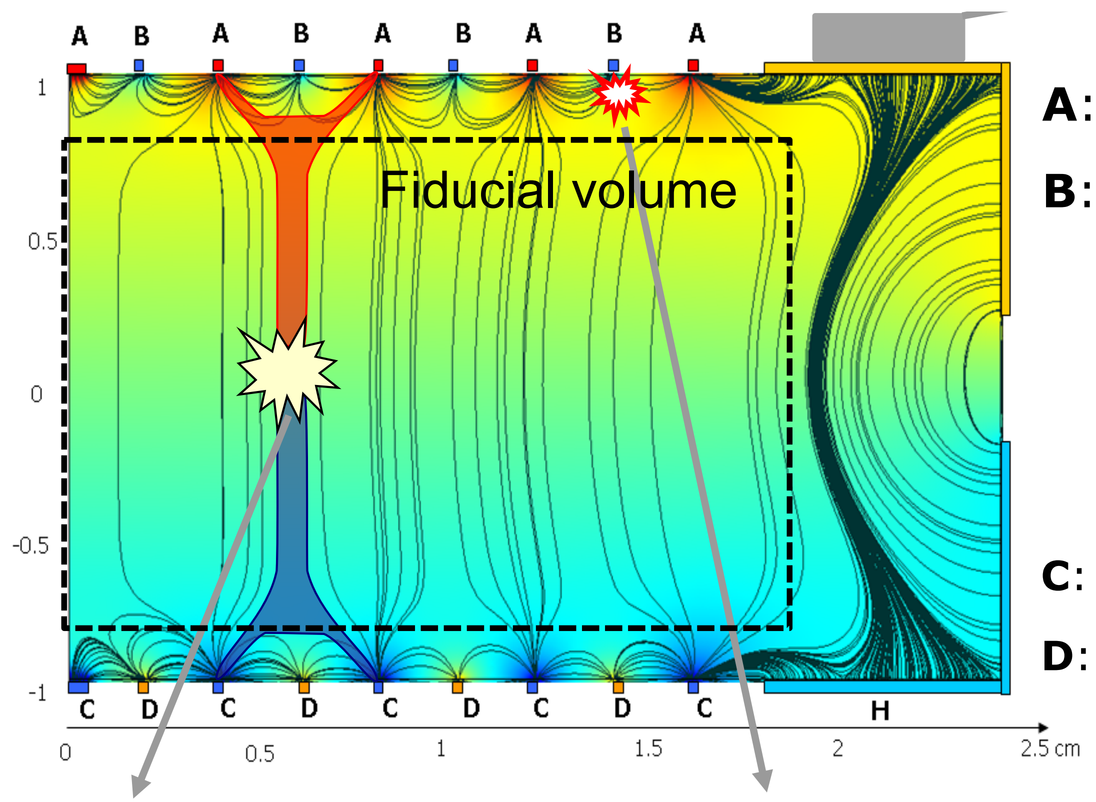
Planned Setup

- cryostat volume of up to 400 kg target
- 200 kg experiment with sensitivity of 8×10^{-47} cm^2 at 60 GeV/c^2
- Pb/Cu shielding for external radiation
- increased PE shielding (neutrons)
- possible neutron veto

- Calibration runs at Soudan indicate that the new iZIPs have good enough surface rejection capabilities for a 200 kg experiment at SNOLAB to run 4 years! **(arXiv:1305.2405)**

EDELWEISS III

NTD themal senor



Bulk/Fiducial event
Charge collected on electrodes A&C

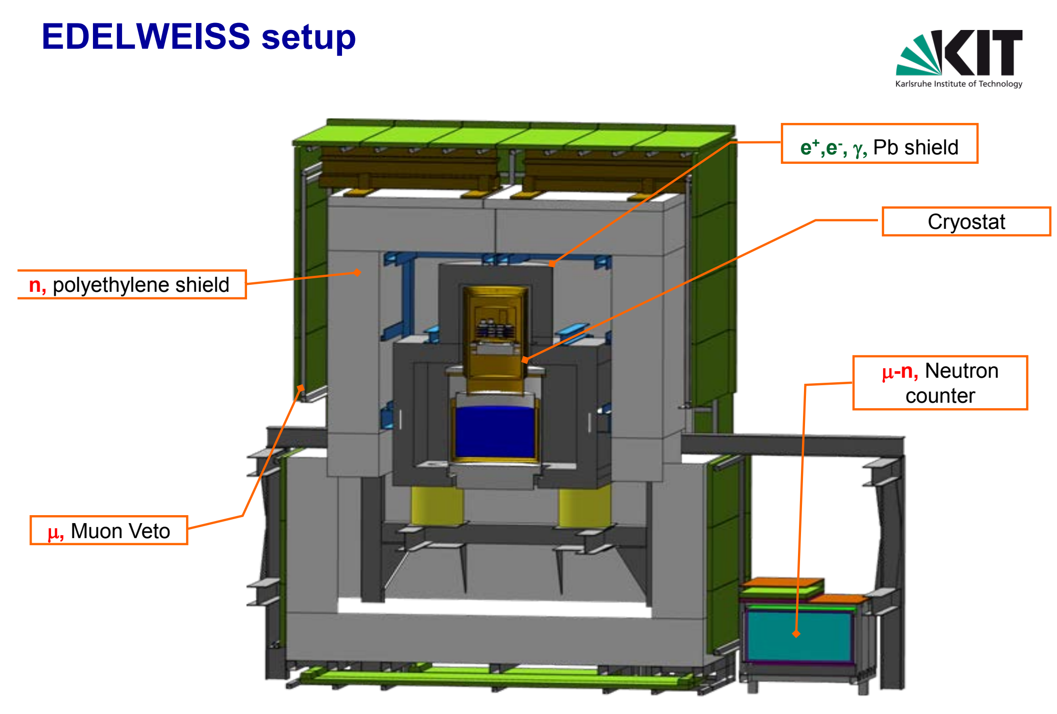
Surface event
Charge collected on electrodes A&B

- Discrimination from ionization yield and charge collection symmetry.

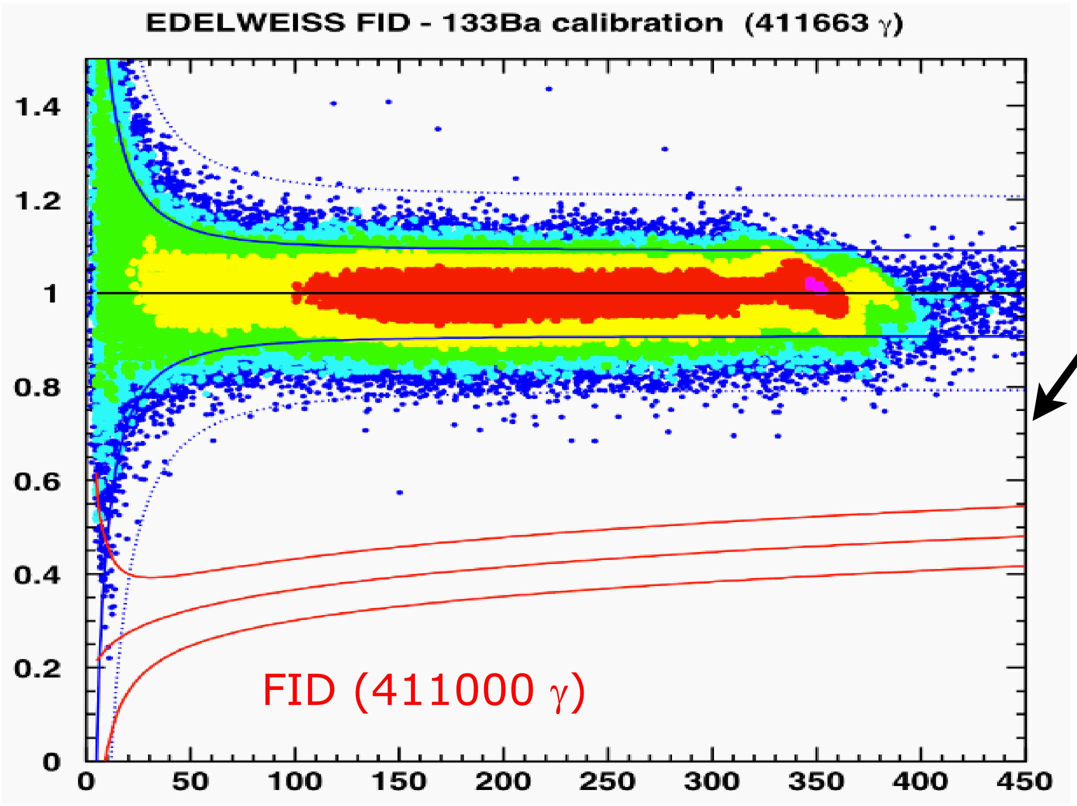
- Located in the Laboratoire Souterrain de Modane (LSM) between Italy and France.

or

- Detectors instrumented with electrodes to measure charge and NTD thermal sensors to measure phonon signal.

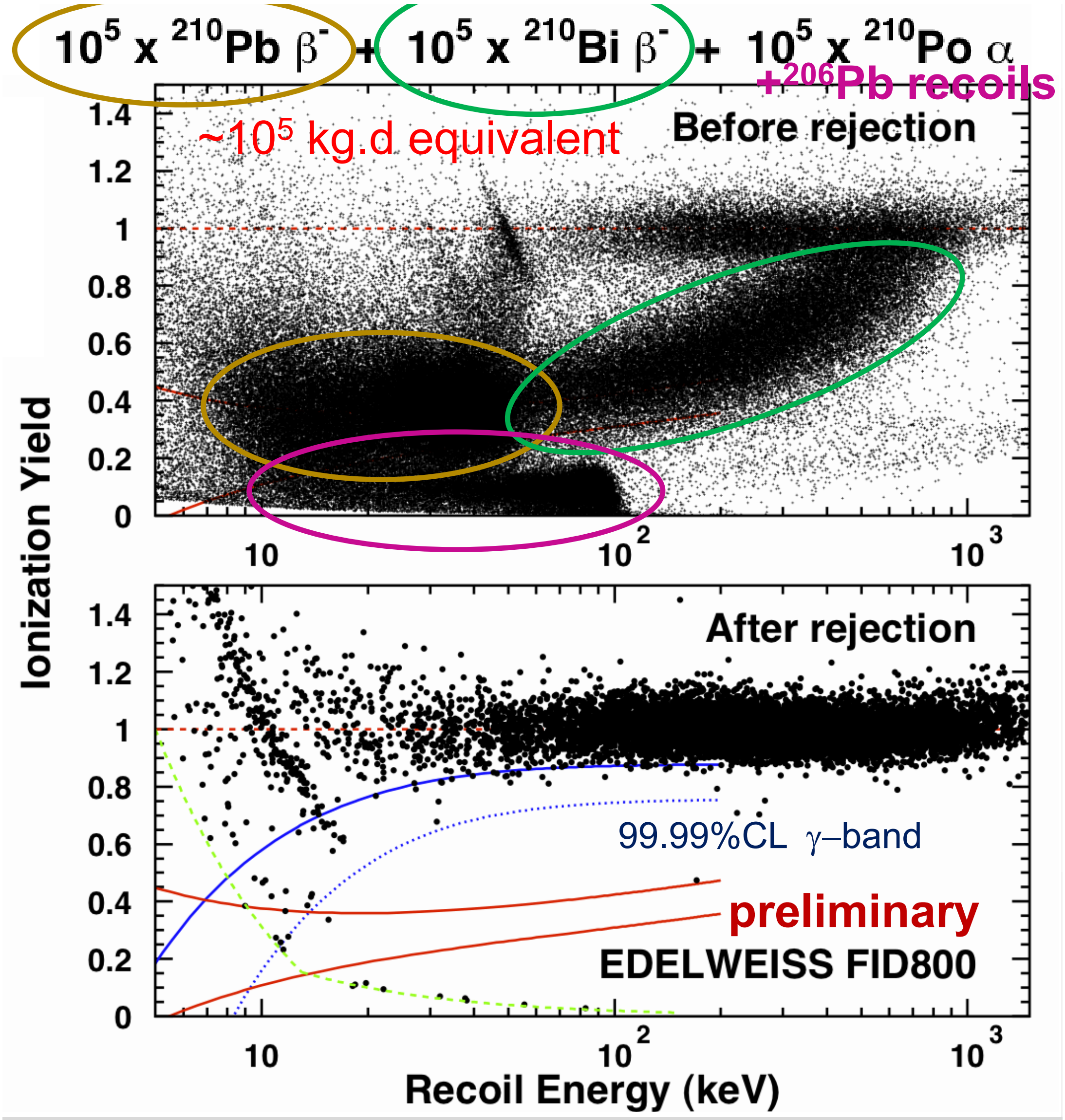


EDELWEISS III



- Improvements to γ-discrimination

- Improvements to surface event discrimination
  - < 4 x 10^{-5} misID events per kg-d (E_r > 15 keV)



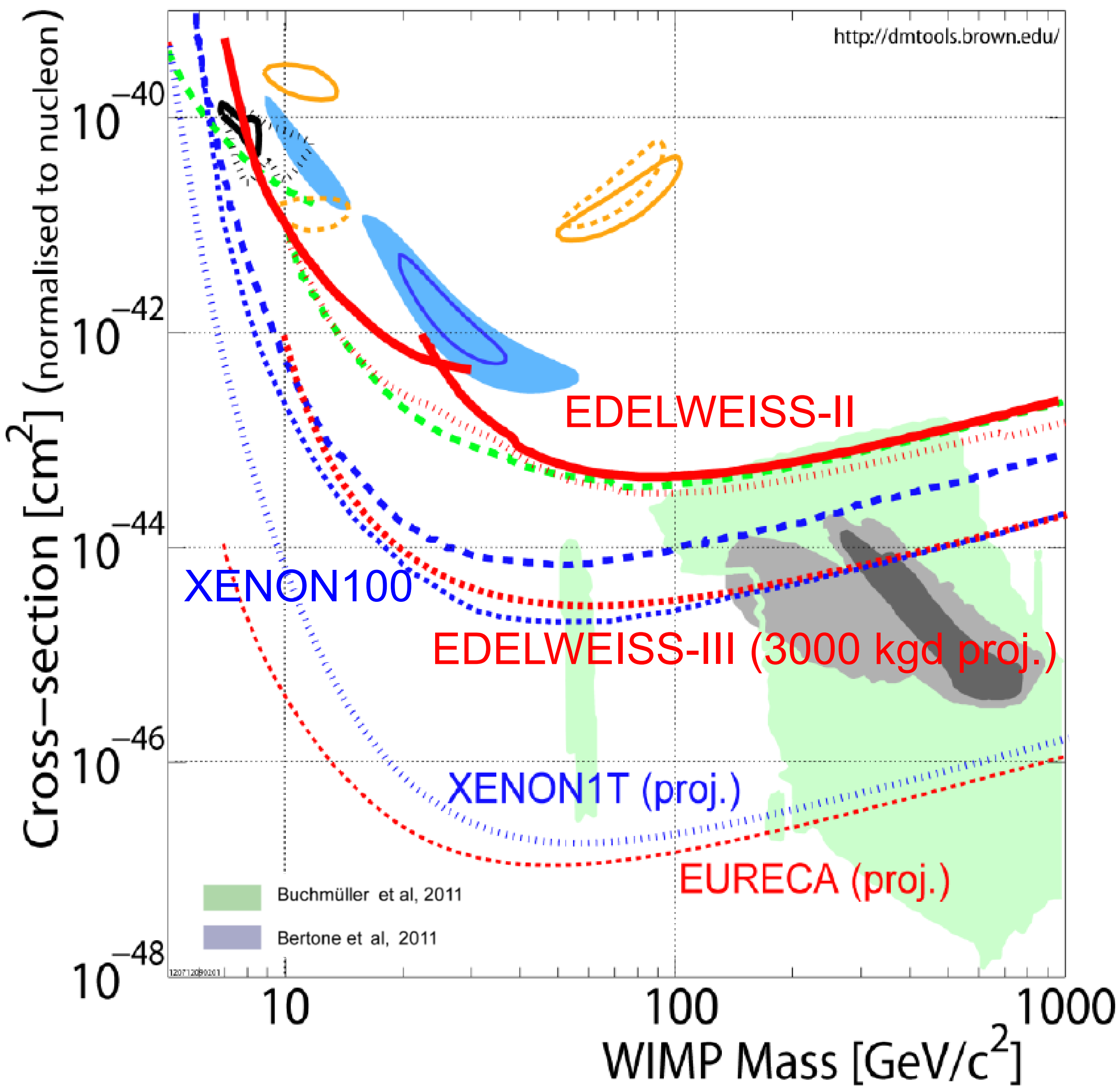
EDELWEISS III - Projections

Sept. 2013

- EDELWEISS III Commissioning runs underway
- 15 FID detectors of mass 800g each
- upgraded cryostat, readout electronics and kapton cables
- New PE shield and copper screens

End of 2013

- Fully equiped cryostat with 40 FID detectors of 800g mass each.

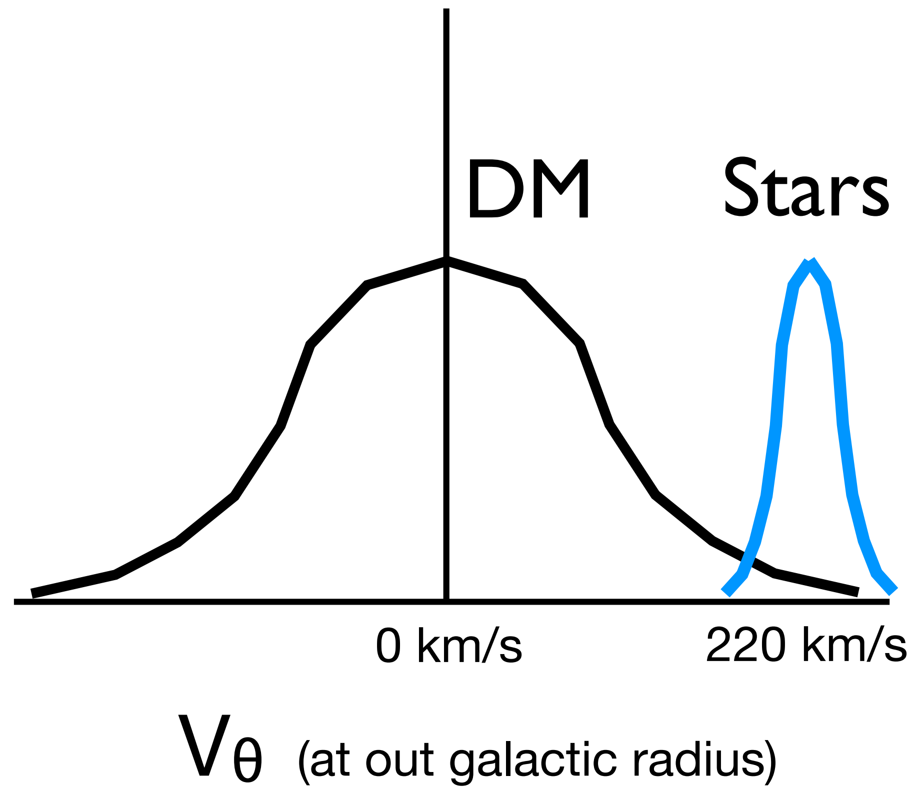


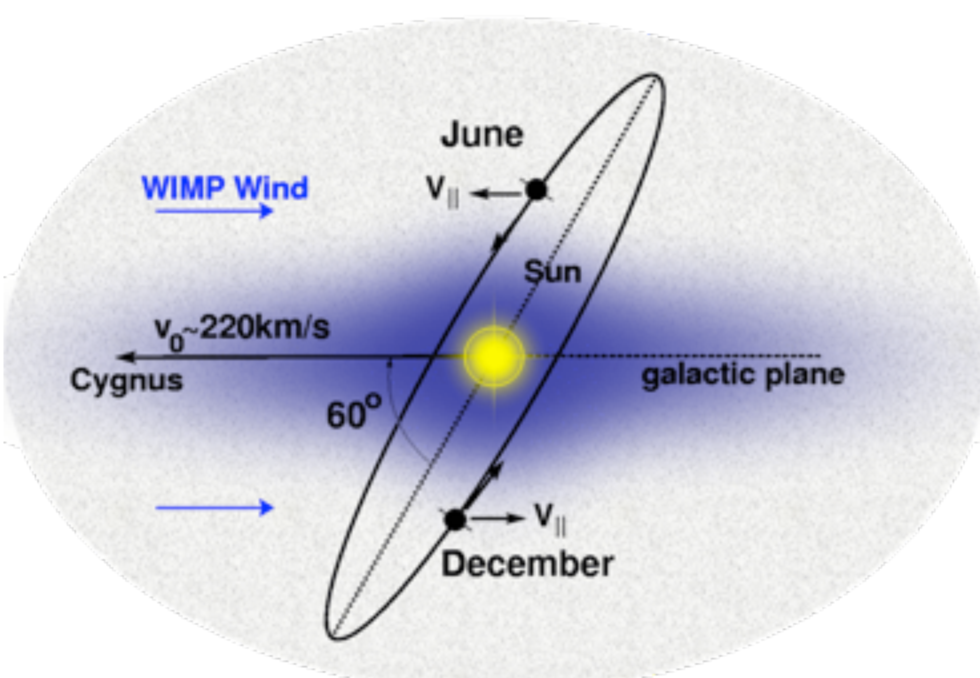
The Experiments Part 2: Addressing a Long Standing Issue

DAMA/LIBRA Modulation Signal

Signal Modulation

- Baryons travel together in roughly circular orbits with small velocity dispersion
- Dark matter particles travel individually with no circular dependence and large velocity dispersion



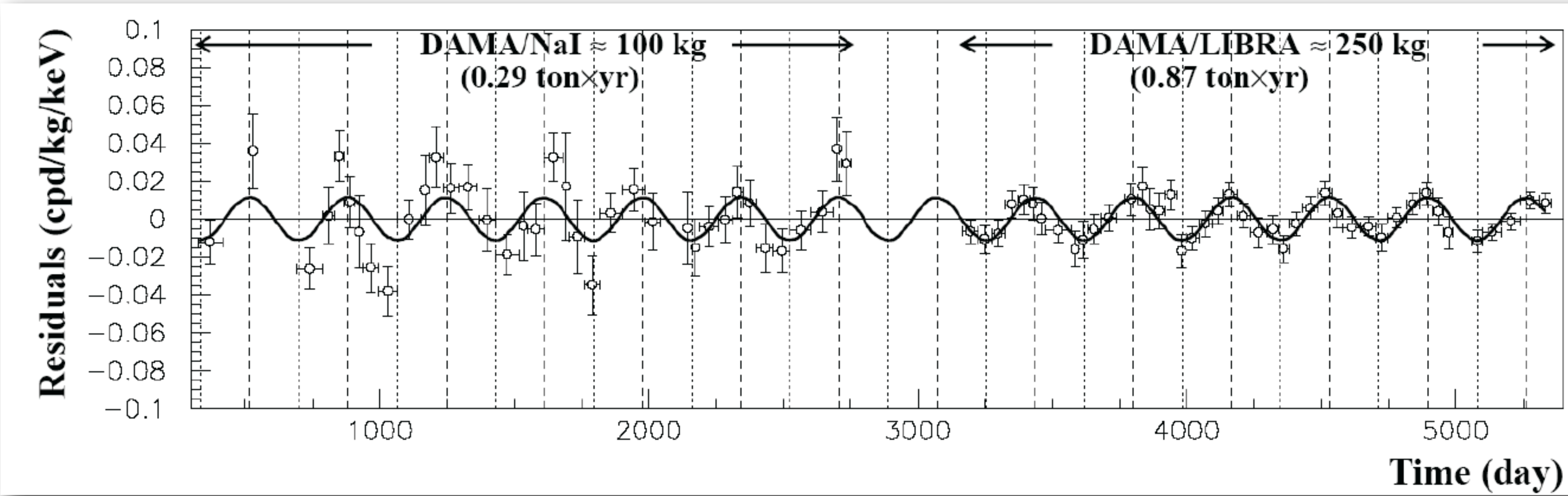


- As a result, the flux of WIMPs passing through Earth modulate over the course of a year as Earth rotates around the sun.

DAMA/LIBRA

- **DAMA**
  - 100 kg NaI array operated from 1996 - 2002 in Laboratori Nazionali del Gran Sasso.
  - Measures scintillation from particle interactions in detectors.
  - No discrimination between nuclear and electron recoils
  - Positive results reported in 1998.
- **LIBRA**
  - 250 kg array operating since 2003 with first results in 2008.

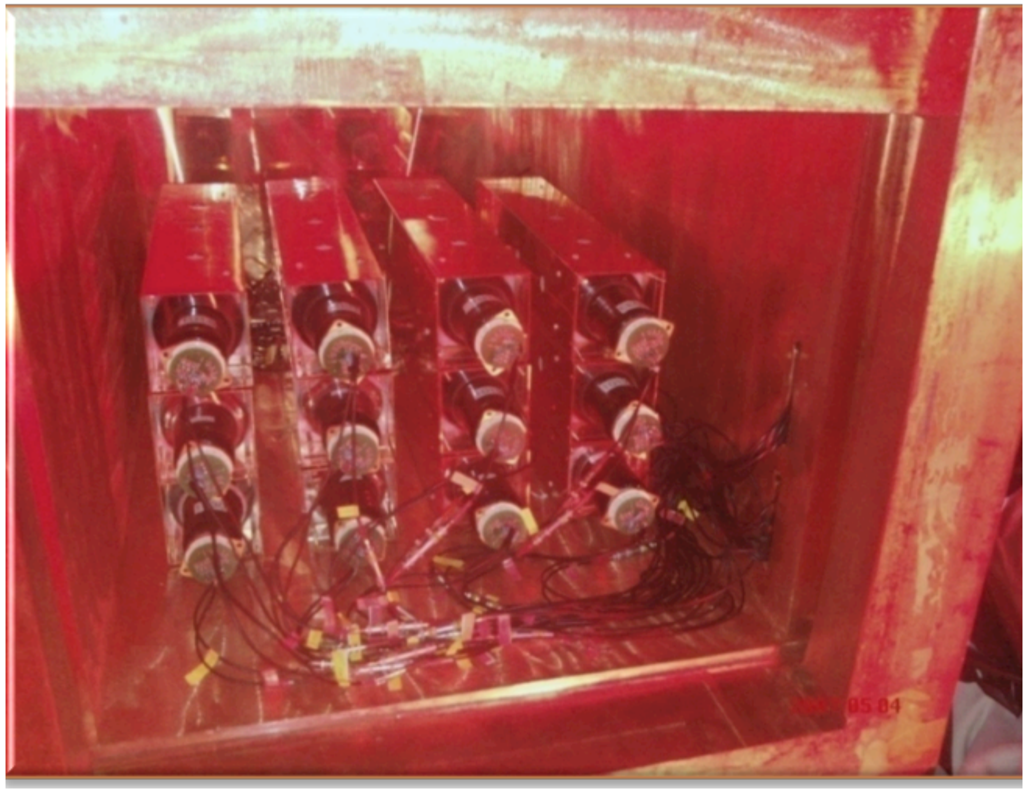
DAMA/LIBRA

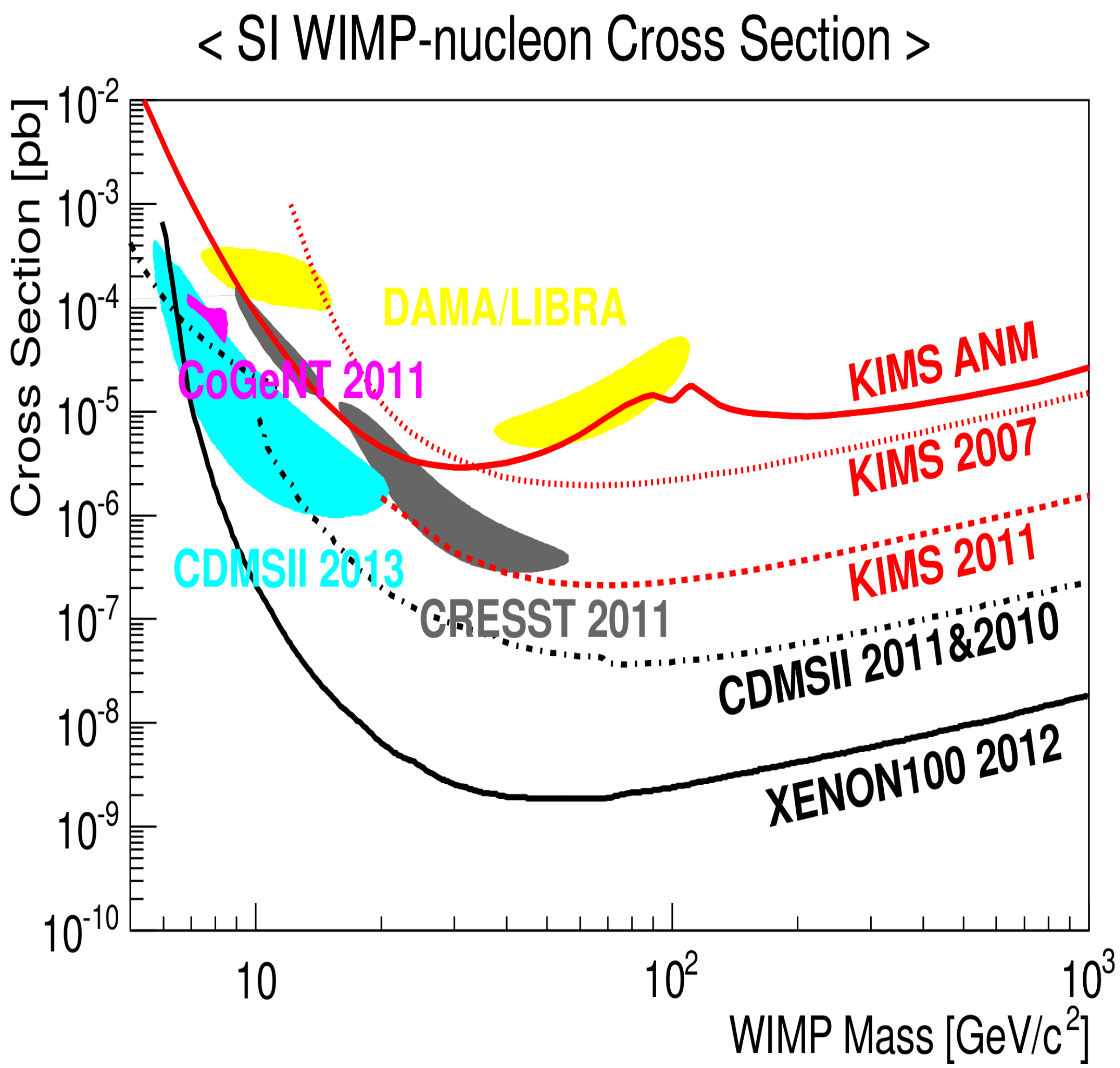


- Modulation has been observed over 13 cycles.
- Significance is 8.9σ.
- Signal is observed only in lowest energy bin.

KIMS

- Direct comparison to DAMA annual modulation signal using CsI(Tl) crystals
  - Pulse shape discrimination also possible
- 12 crystals (104.4 kg) installed
- Data taking from Sept 2009 - Feb. 2012

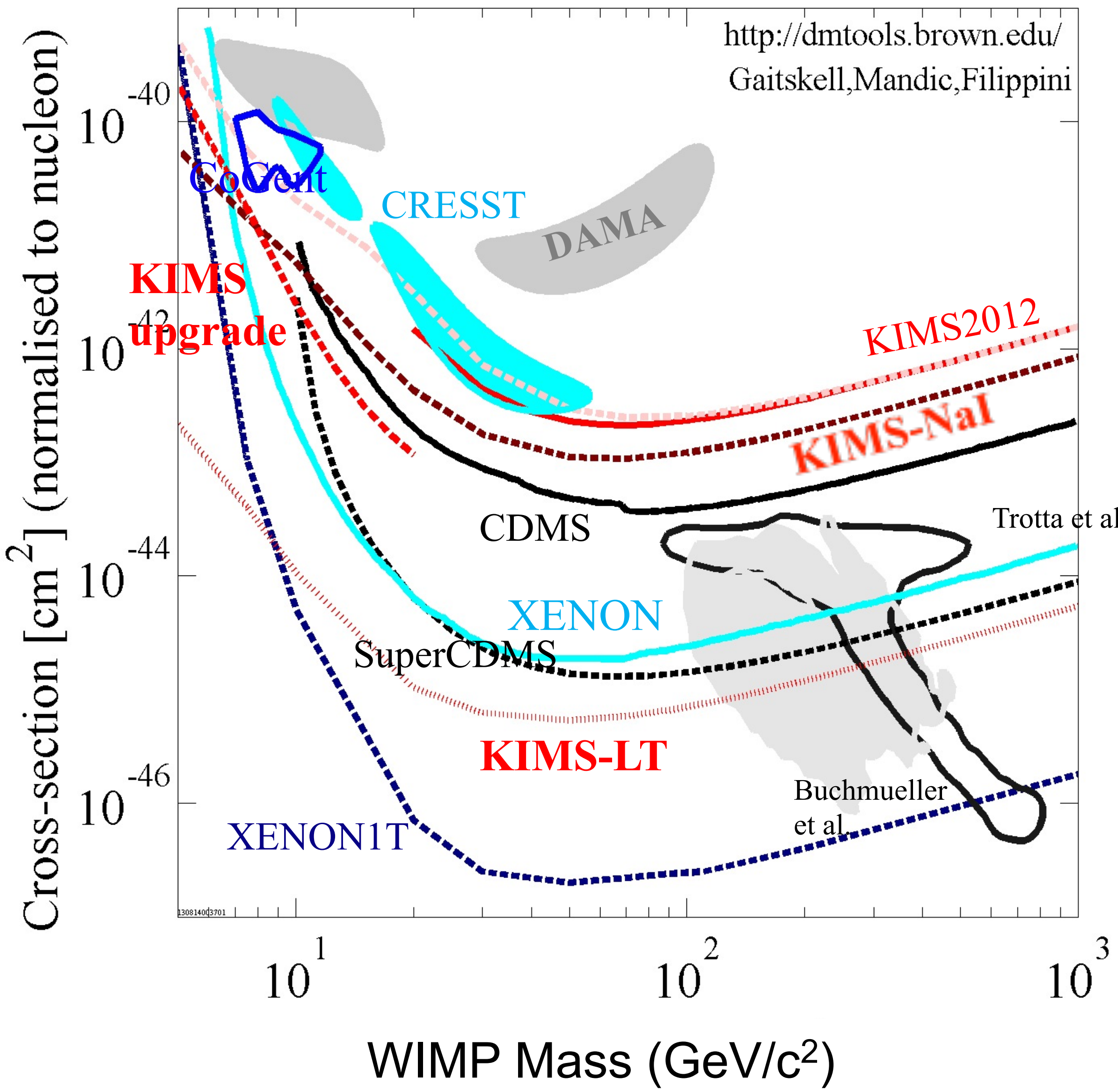




- Pulse shape discrimination excludes DAMA/LIBRA - **PRL 108, 181301 (2012)**
- No annual modulation is observed.

KIMS

- **KIMS-CsI:** Upgrade of CsI(Tl) crystal detector
  - Lower threshold ~ 1.5keV, < 1dru, counts/(keV kg day).
- **KIMS-NaI:** new NaI(Tl) detector
  - Duplicate DAMA experiment with ultra-low background NaI(Tl) crystals.
  - 200kg run in 2015-2016

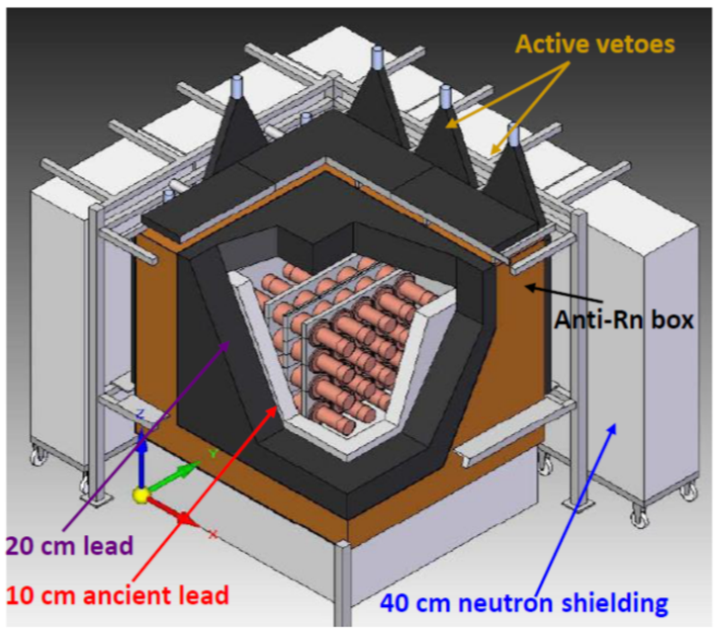


- **KIMS-LT**
  - Use scintillating bolometer such as $^{nat}Ca^{nat}MoO_4$ crystals ~ 200 kg year.
  - High sensitivity to low mass WIMP.
  - Operations in 2019-2022

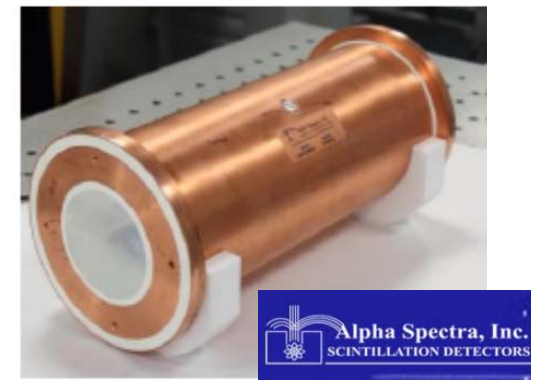
ANAIS

Goal:

250 kg of NaI(Tl) detectors to study the annual modulation effect at the Canfranc Underground Laboratory, LSC (Spain)
Same target and technique used by DAMA/LIBRA



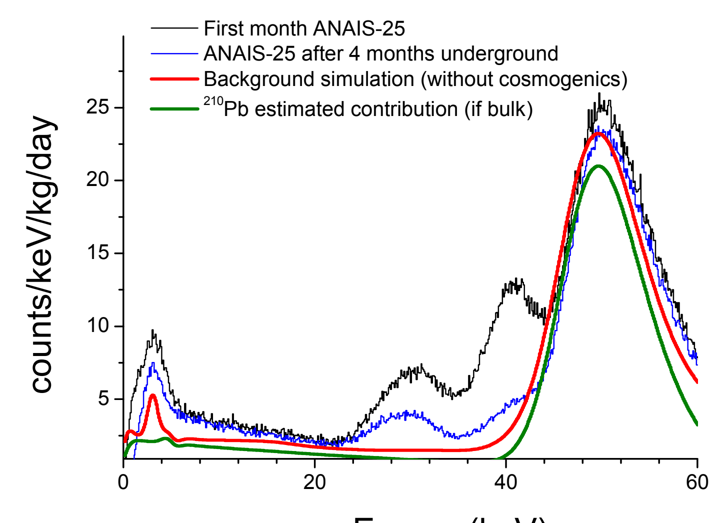
2 prototypes taking data at LSC – 25 kg (ANAIS-25)



Ham PMT – R12669 SEL coupled at LSC clean room

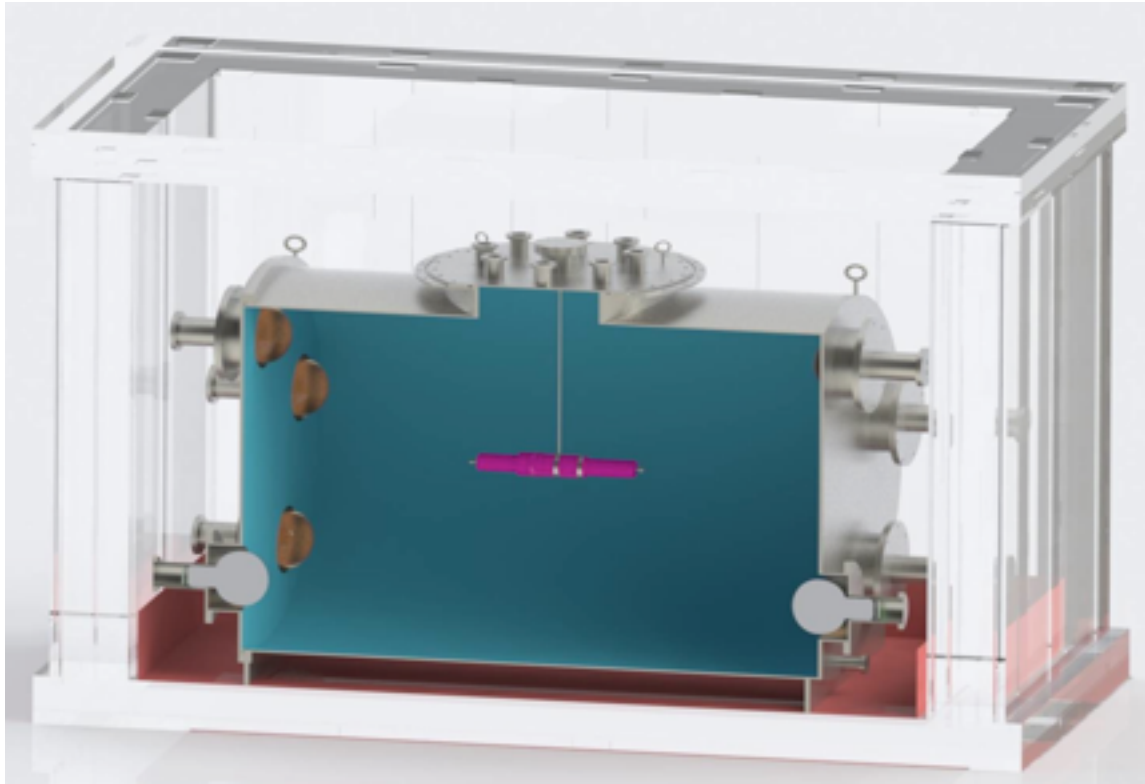
ANAIS-25 PRELIMINARY RESULTS

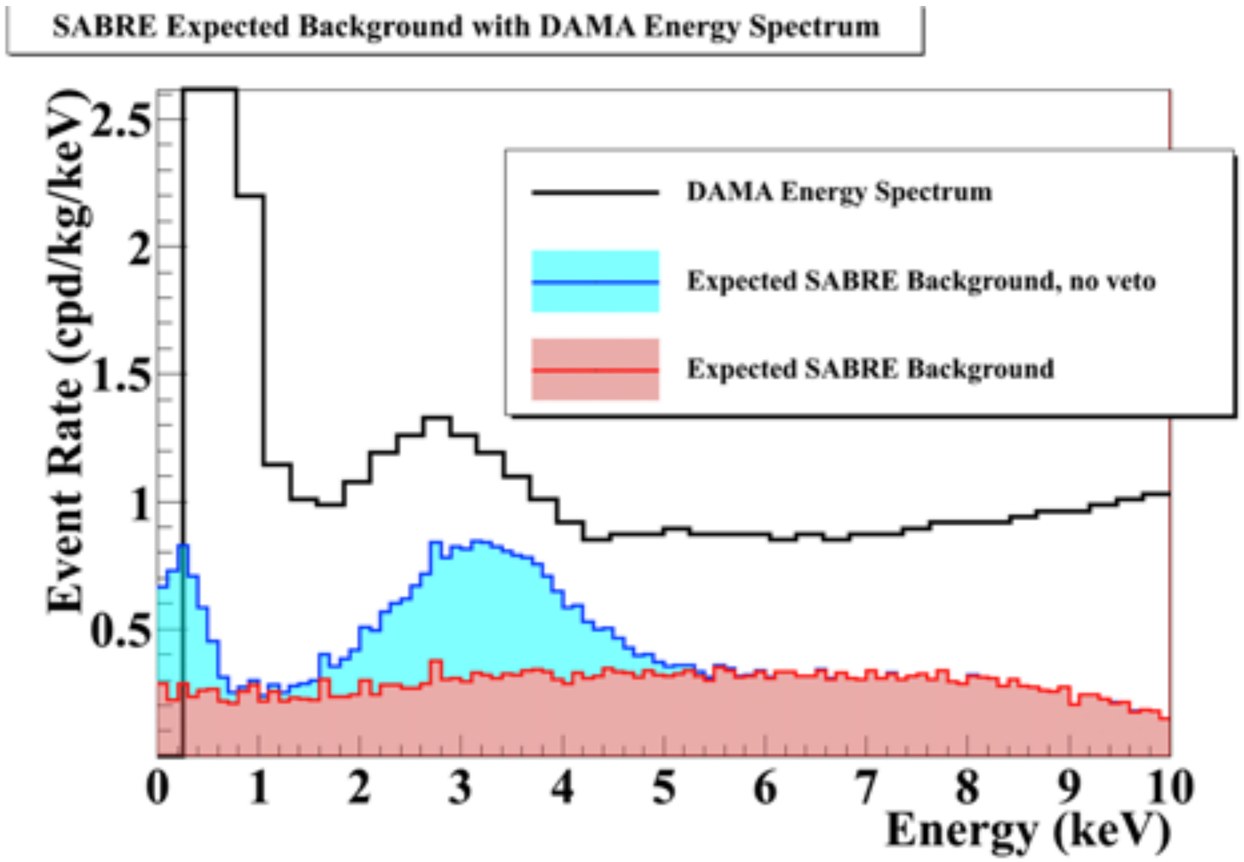
- Excellent light collection efficiency: 12-16 phe/keV
- ^{40}K bulk NaI content = 41.7 ± 3.7 ppb
- Problem with ^{210}Pb too high level
- Cosmogenic activation still decaying & low energy events selection not yet fully developed



SABRE

- **S**odium-iodide with **A**ctive **B**ackground **RE**jection
- Plan to use an active muon veto to drastically reduce the number of gamma backgrounds





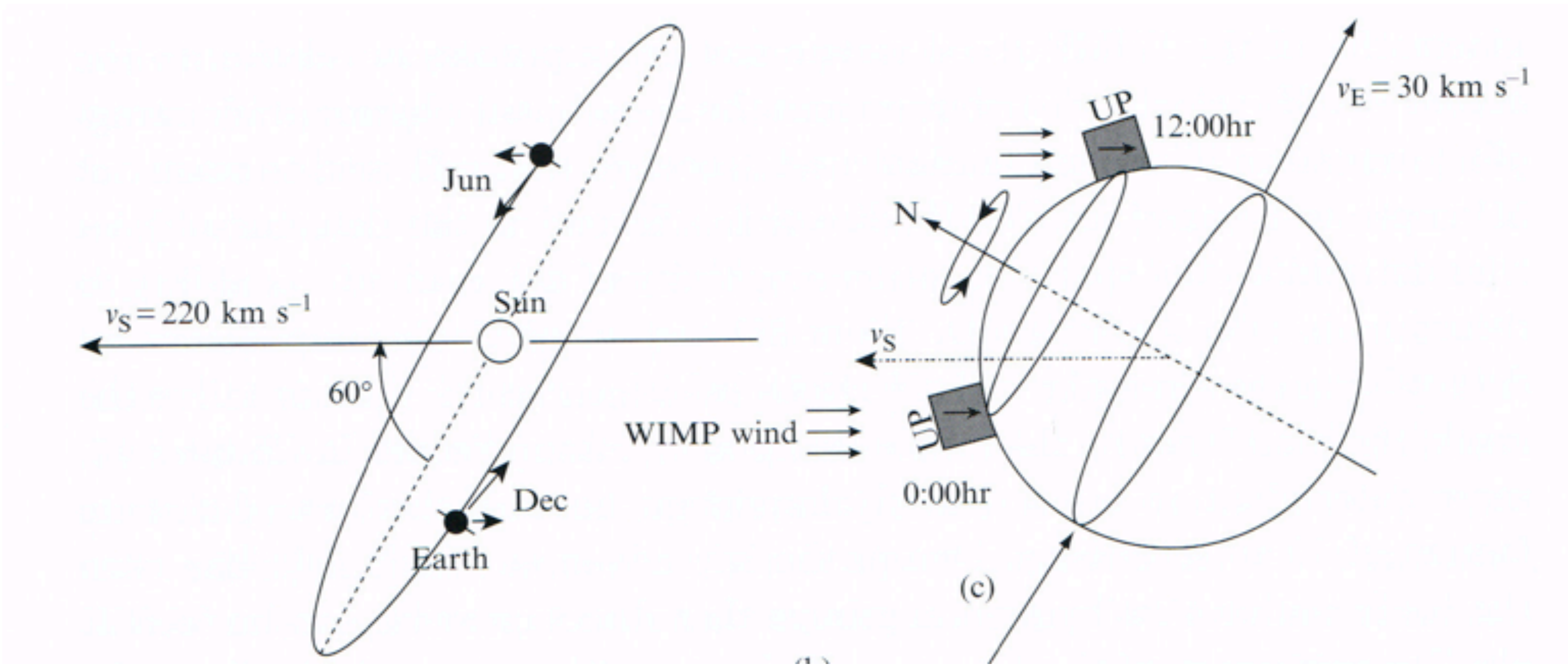
- 1460 keV gamma from decay of ^{40}K can deposit 3 keV of energy in a crystal (arXiv: 1210.5501)
- Currently in building phase.

\

The Experiments Part 3: The Search Continues ....

Directional Searches and Techniques Involving Superheated Fluids

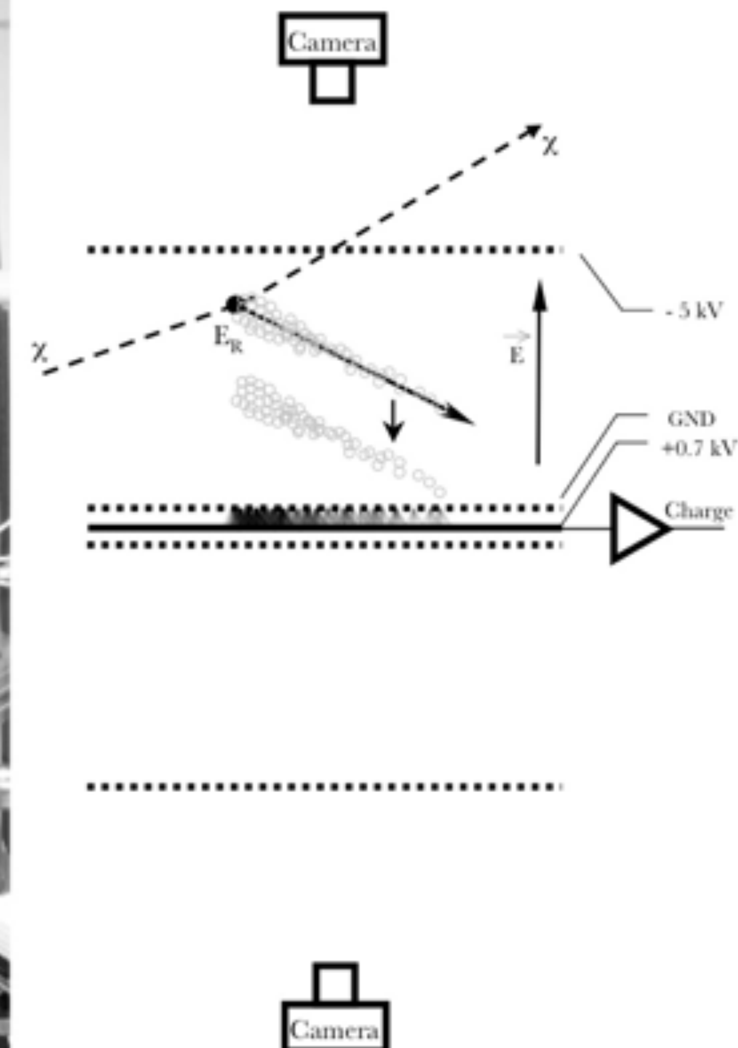
Directional Searches



- A detector at 45 degree latitude will see the dark matter wind oscillate in direction over the course of a day.
- This is a sidereal (tied to stars) effect, not diurnal (tied to sun).

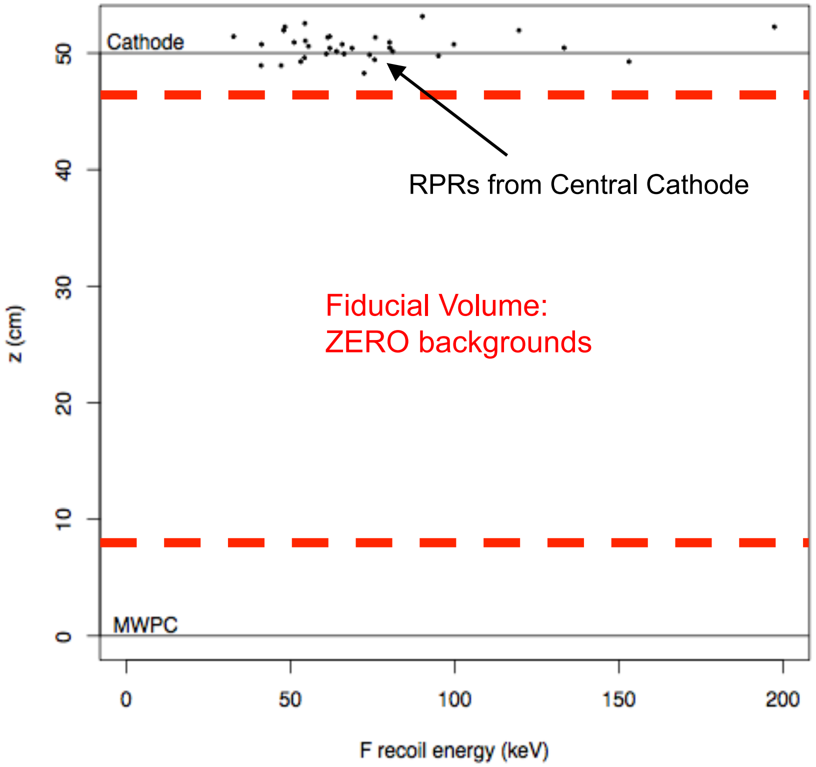
DMTPC

- 10 L prototype underground at WIPP in Carlsbad, NM, USA
- Filled with CF_4 gas to probe the WIMP-^{19}F spin-dependent cross-section
- Dark matter is identified by directional signal.
- In additional, electron recoils can be identified by their low ionization density (i.e. stopping power).
- “4Shooter” 20 L experiment at MIT
- “DMTPCino” 1 m^3 funded by the DOE and NSF



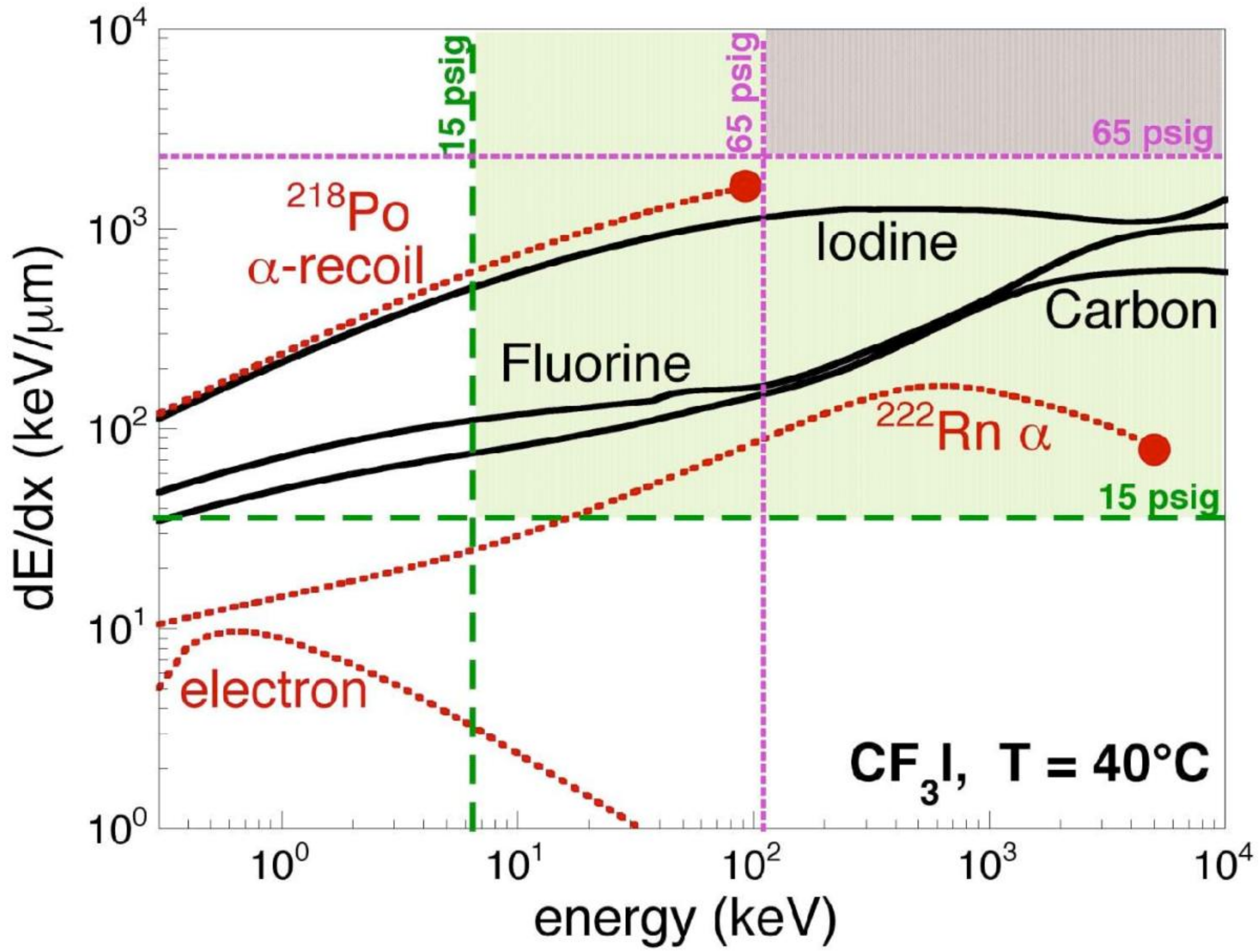
DRIFT

- DRIFT-IId (800 L fiducial volume) operating in Boubly, UK.
  - Negative ion TPC with MWPC wire readout. with a 30 Torr CS_2 + 10 Torr CF_4 target.
  - DRIFT is now running with "zero backgrounds" and with sensitivity 10x lower than previously.
- A completely redesigned DRIFT-IIe detector will be deployed in early 2014.
  - Enhancements include "transparent", stackable MWPCs, enhanced resolution, every-wire readout and redesigned field cage.
- Plans to submit proposal for an expandable 24 m^3 experiment Fall 2013.



Particle Detection in Bubble Chambers

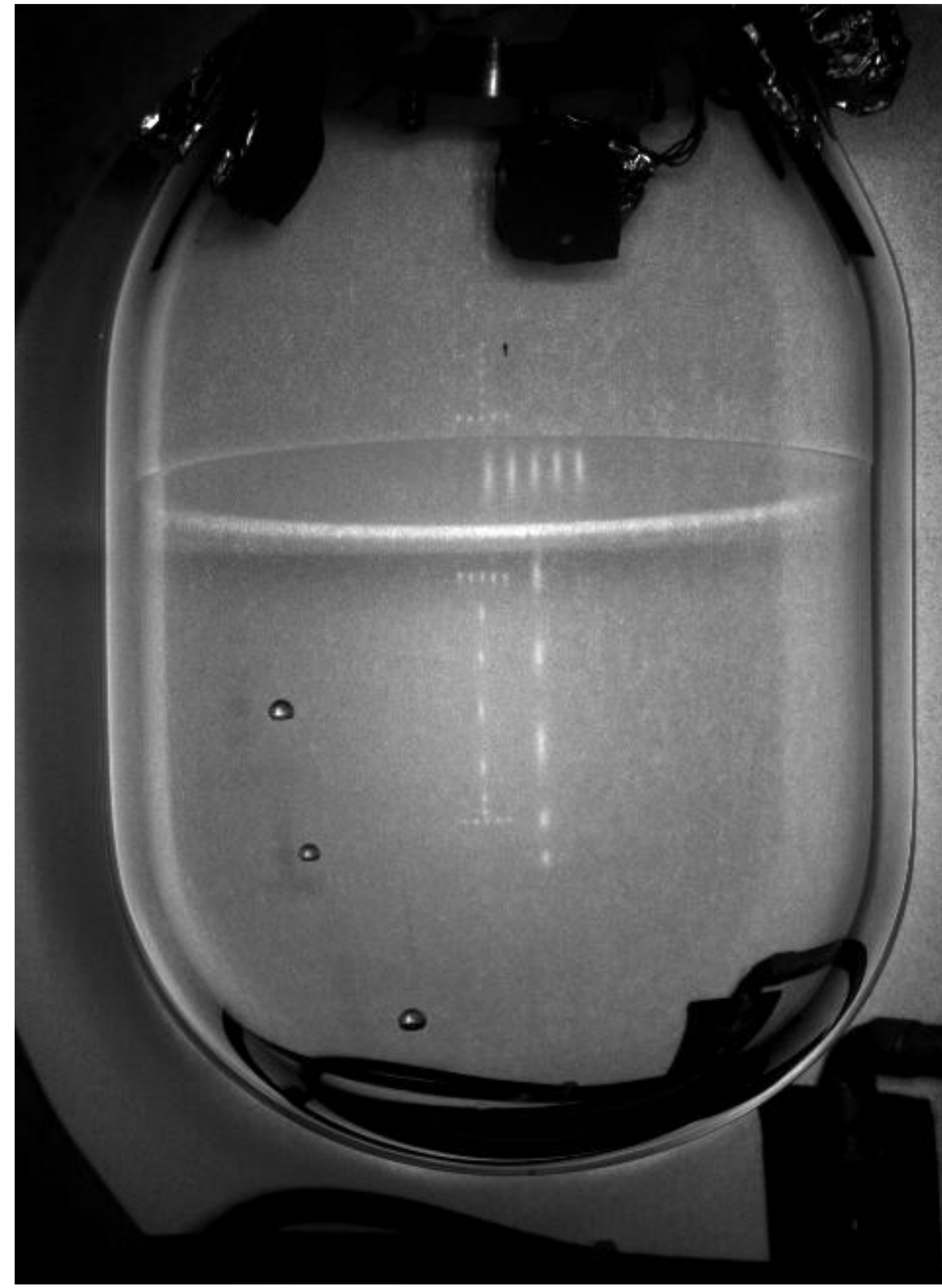
- A bubble chamber is filled with a superheated fluid in a metastable state.
- A particle interaction with energy deposition greater than E_{th} in a radius $< r_c$ results in an expanding bubble.
- A smaller or more diffuse energy deposition will result in a bubble that immediately collapses.



- You can "tune" the chamber to make bubbles for nuclear recoils and not for electron interactions.

COUPP

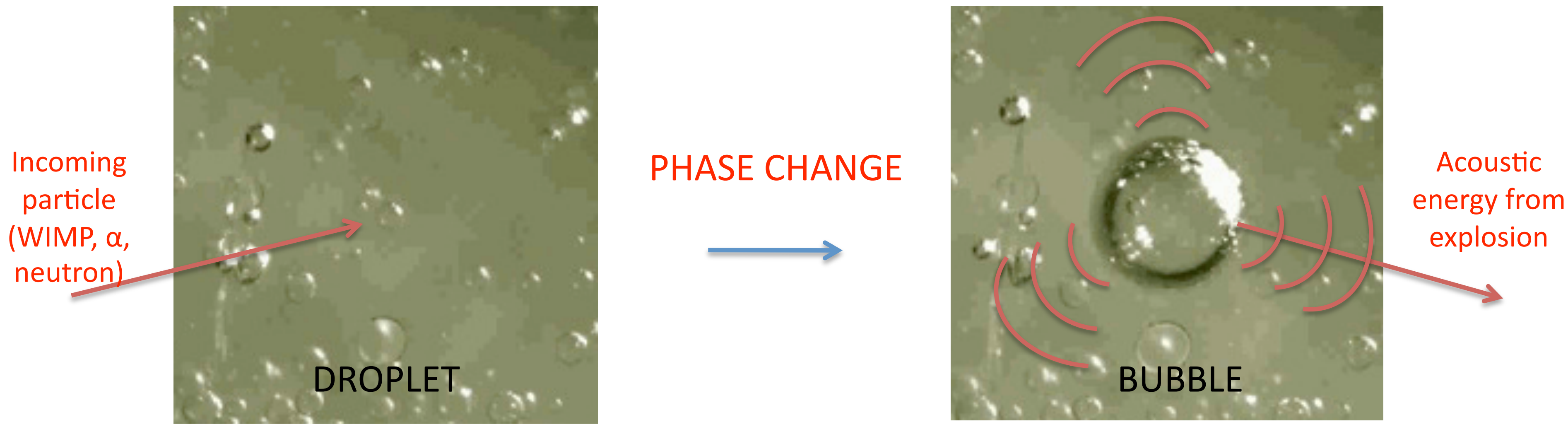
- Superheated fluid CF_3I located in SNOLAB, Canada.
  - F for spin-dependent interactions
  - I for spin-independent interactions
  - Target can be swapped out
- Bubbles are observed by two cameras and piezo-acoustic sensors
- Better than 10^{-10} rejection of electron recoils
- Alphas can be a concern. However, they can be rejected by acoustic discrimination.

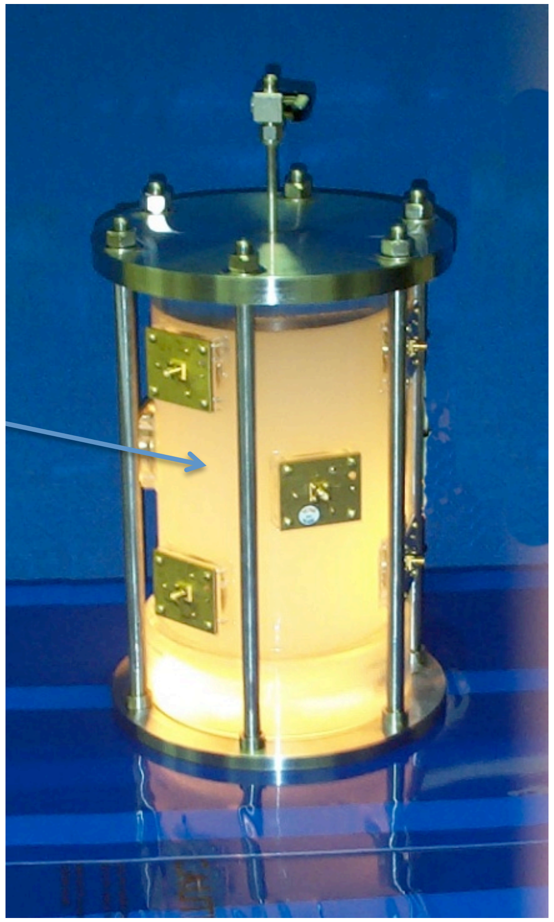


Jackson - Mon. DM II

PICASSO

- A superheated liquid detector using a C_4F_{10} target.
- Location: SNOLAB, Canada
- C_4F_{10} droplets are suspended in polymerized gel in a 4.5L acrylic vessel. Experiment contains 32 modular detectors.
- Acoustic energy deposition of incoming particles is measured by 9 piezoelectric sensors.
- New results are in preparation.
- Total exposure will be ~800 kg-d by end of 2013.





COUPP/PICASSO/PICO

COUPP-60

- Filled with 37 kg of CF_3I on April 26, 2013
- First bubble May 1, 2013 (radon decay)
- Installation completed May 31, 2013
- Started first physics run in late June
- Increase target mass to 75 kg in fall/winter
- Ultimate goal of 3 year run (50000 kg-days exposure)

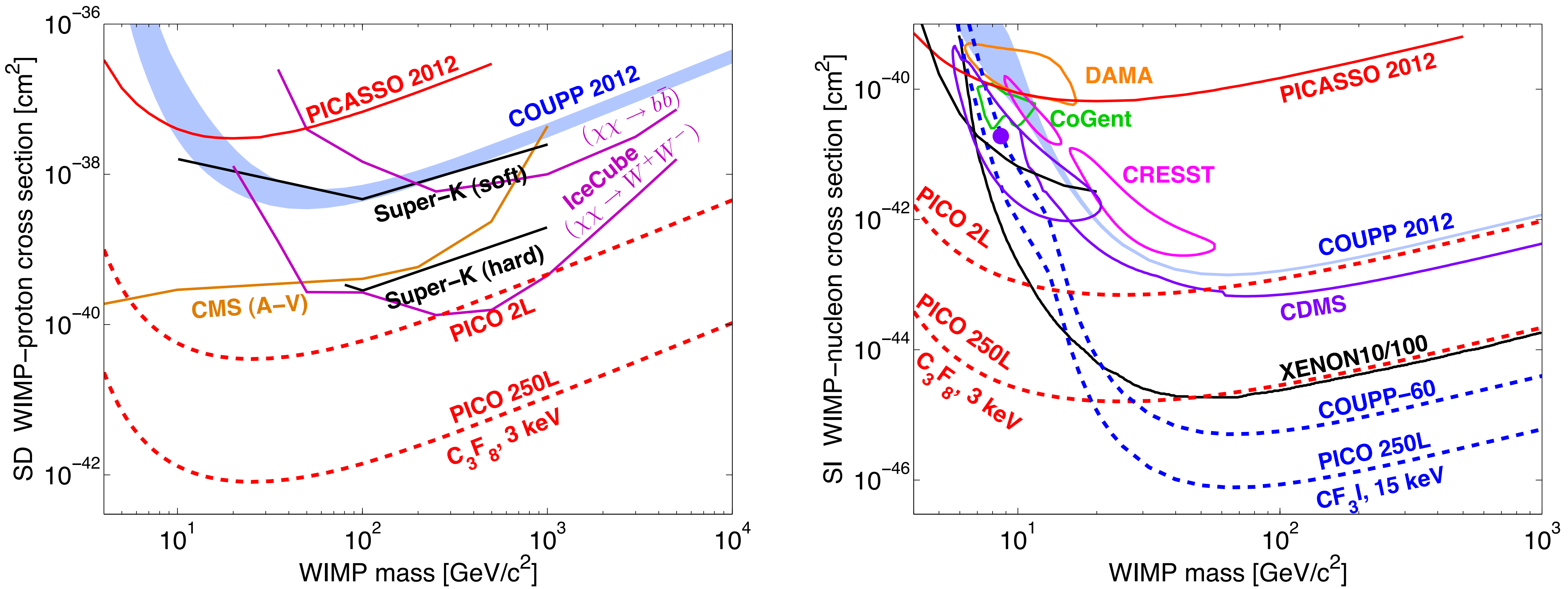
PICO-lite

- Joint effort between COUPP & PICASSO
- C_3F_8 chamber (2L) in existing COUPP-4 infrastructure at SNOLAB
- 3 keV threshold
- Excellent low-mass WIMP and SD coupling sensitivity
- CDMS-Si result gives 1 event/day in COUPP-4lite
- Deploy September 2013

PICO-250

- 250L bubble chamber design effort
- Well developed Conceptual Design
- Straightforward scale-up from COUPP-4 and COUPP-60
- Begin construction in 2014-2015

COUPP/PICASSO/ PICO Projections and Limits



- COUPP Limits: **Phys. Rev. D 86, 052001 (2012)**
  - 553 kg-days total exposure (4.0-kg CF_3I)
- PICASSO Limits: **Phys Lett B 711(2) (153-161)**
  - 114 kg-d exposure (10 modules, 0.72 kg of ^{19}F).

Other Experiments

CUORE

Biassoni - Mon. DM II

Gaseous Detectors

Gerbier - Mon. DM II

NEXT

Renner - Wed. DM V

DAMIC

Chavarria - DM VI

TEXANO

Lin - Thurs. DM VIII

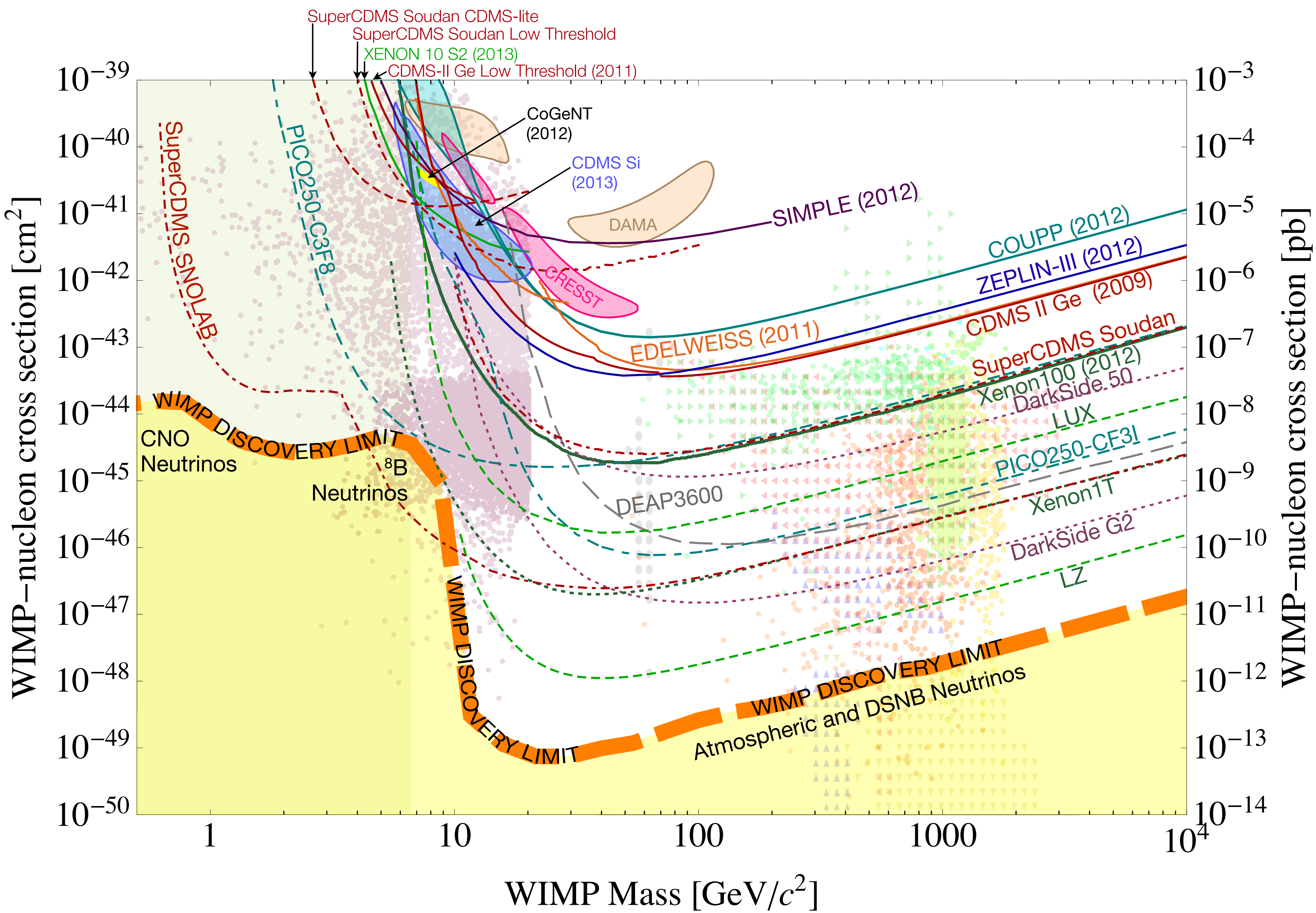
CDEX

Yue - Thurs. DM VIII

Kamland-PICO

Fushimi - Thurs. DM VIII

Where Are We Going?



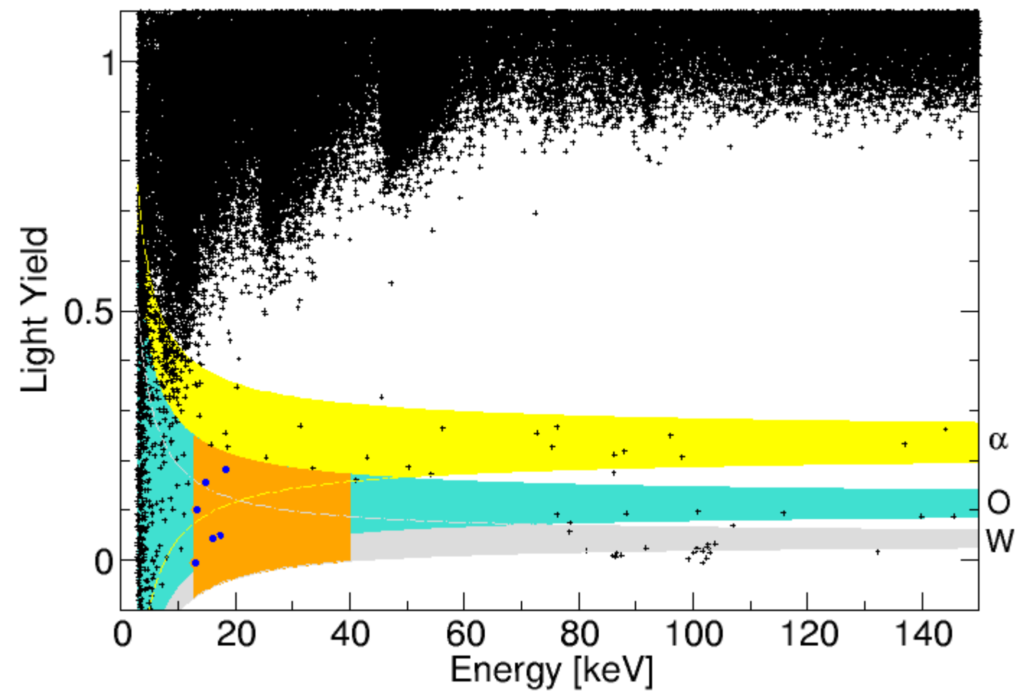
Summary/Outlook

- Dark matter experimentalists have come up with clever techniques to suppress backgrounds in an attempt to extract a dark matter signal.
- Four experiments have observed excess events. If these events are interpreted as dark matter CDMS Si and CoGeNT are compatible. However, it is difficult to reconcile their results from CRESST and DAMA.
- It is necessary to have several technologies in different locations.
- There are many experiments using different techniques currently running world wide. The techniques employed include solid-state devices, two-phase and single-phase noble liquid detectors, superheated detectors.
- There are many planned upgrades and extensions to existing experiments to achieve greater sensitivity.
- It is an interesting time to be working in this field!

Backup Slides

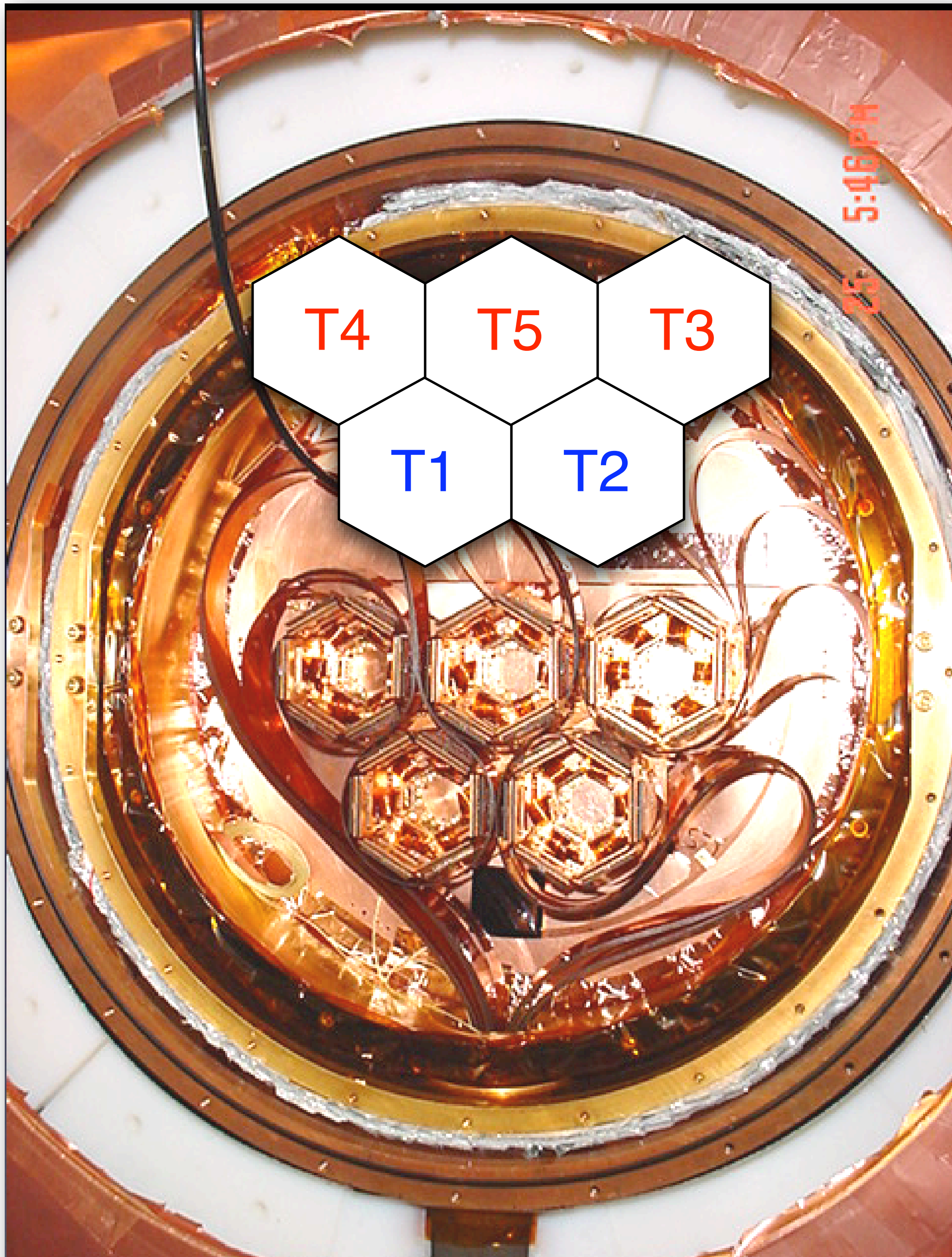
CRESST-II Data

- Net exposure: 730 kg-day (July 2009 - March 2011) from 8 detector modules.
- Observed 67 events in acceptance region (orange).
- Analysis used a maximum likelihood in which 2 regions favored a WIMP signal in addition to predict background.
  - M1 is global best fit (4.7 σ)
  - M2 slightly disfavored (4.2 σ)
- Excess events can not be explained by known backgrounds
- Large background contribution

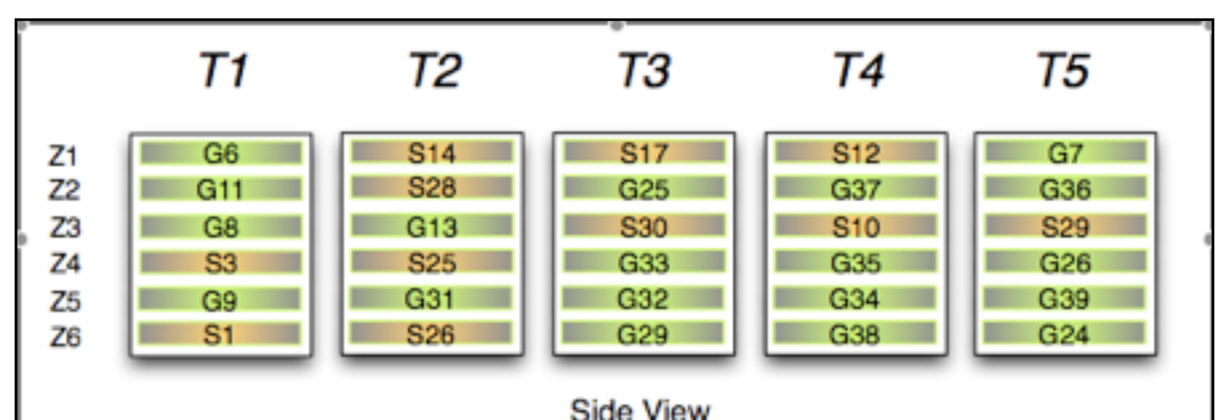


	M1	M2
e/γ events	8.00 ± 0.05	8.00 ± 0.05
α events	$11.5^{+2.6}_{-2.3}$	$11.2^{+2.5}_{-2.3}$
neutron events	$7.5^{+6.3}_{-5.5}$	$9.7^{+6.1}_{-5.1}$
Pb recoils	$15.0^{+5.2}_{-5.1}$	$18.7^{+4.9}_{-4.7}$
signal events	$29.4^{+8.6}_{-7.7}$	$24.2^{+8.1}_{-7.2}$
m_χ [GeV]	25.3	11.6
σ_{WN} [pb]	$1.6 \cdot 10^{-6}$	$3.7 \cdot 10^{-5}$

CDMS II - Si Analysis

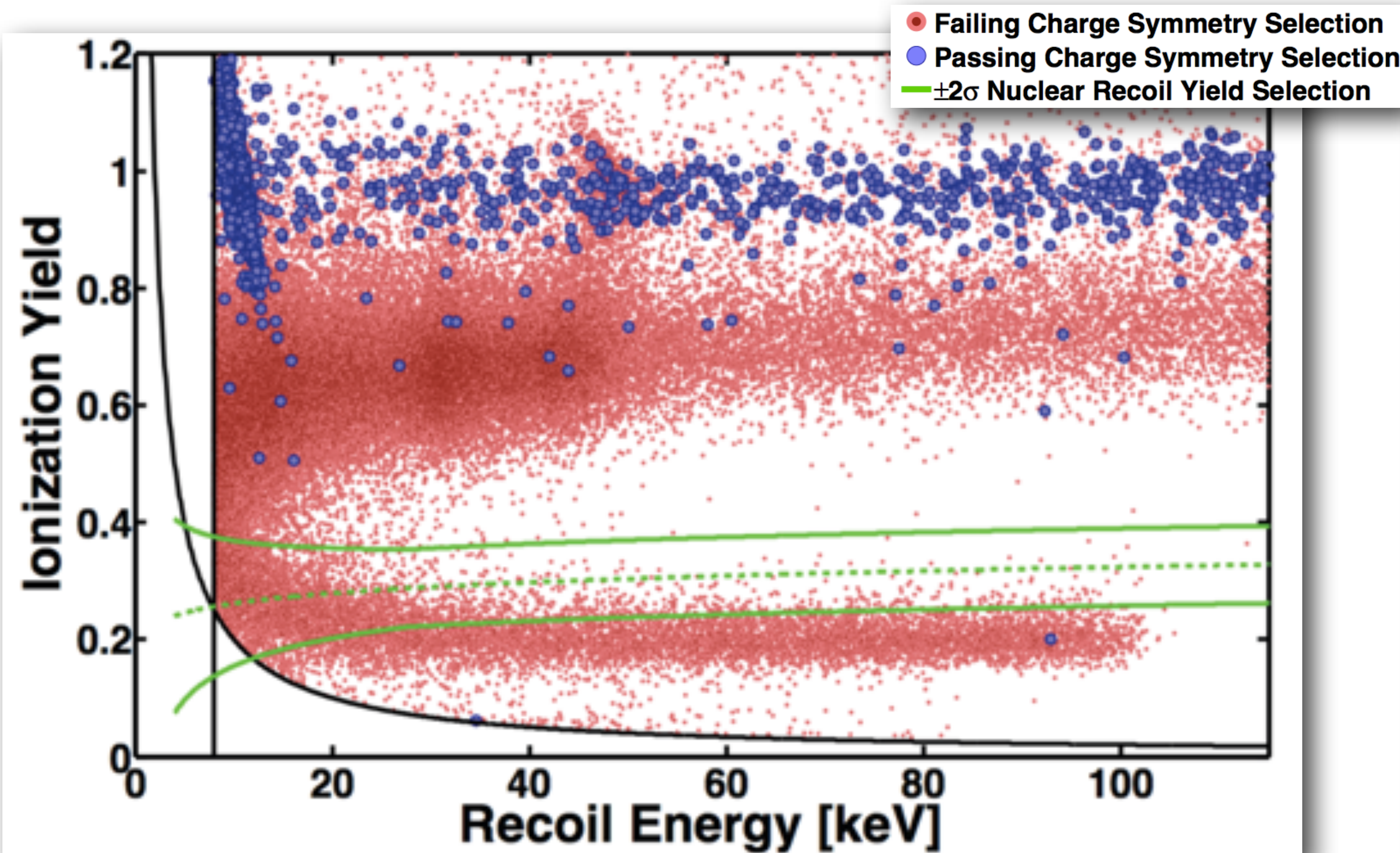


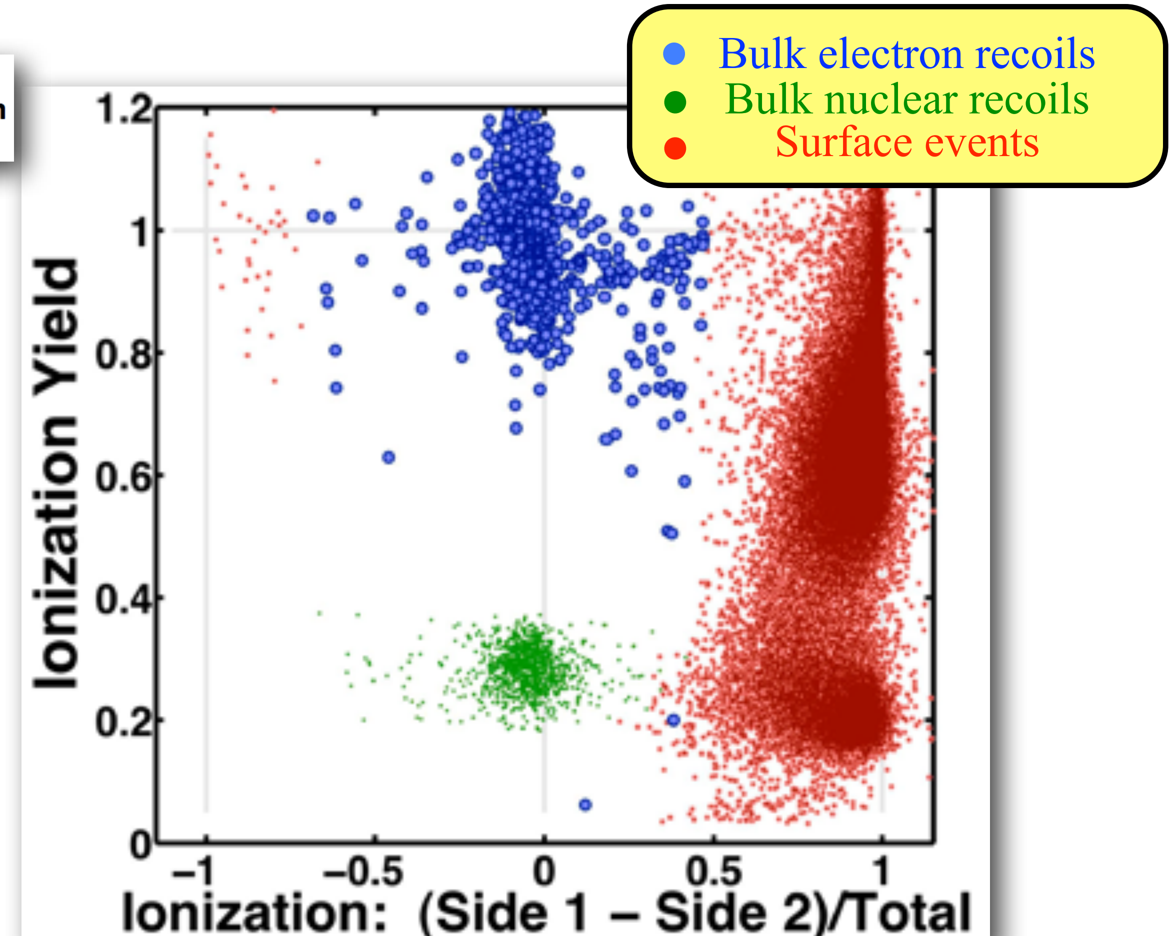
- 30 detectors installed and operated in Soudan from June 2006 - March 2009.
  - ~4.75 kg Ge, ~1.1 kg Si
- Seven Total Data Runs
  - R123- R124 (Oct. 2006 - July 2007)
    - 55.9 kg-days in 6 Si detectors
  - **R125 - R128 (July 2007 - Sep. 2008)**
    - **140.23 kg-days in 8 Si detectors**
  - R129 (Nov. 2008 - Mar. 2009)



SCDMS: ^{210}Pb Test

Two ^{210}Pb sources were deployed with the detectors to test surface rejection capabilities of the new iZIP detectors.

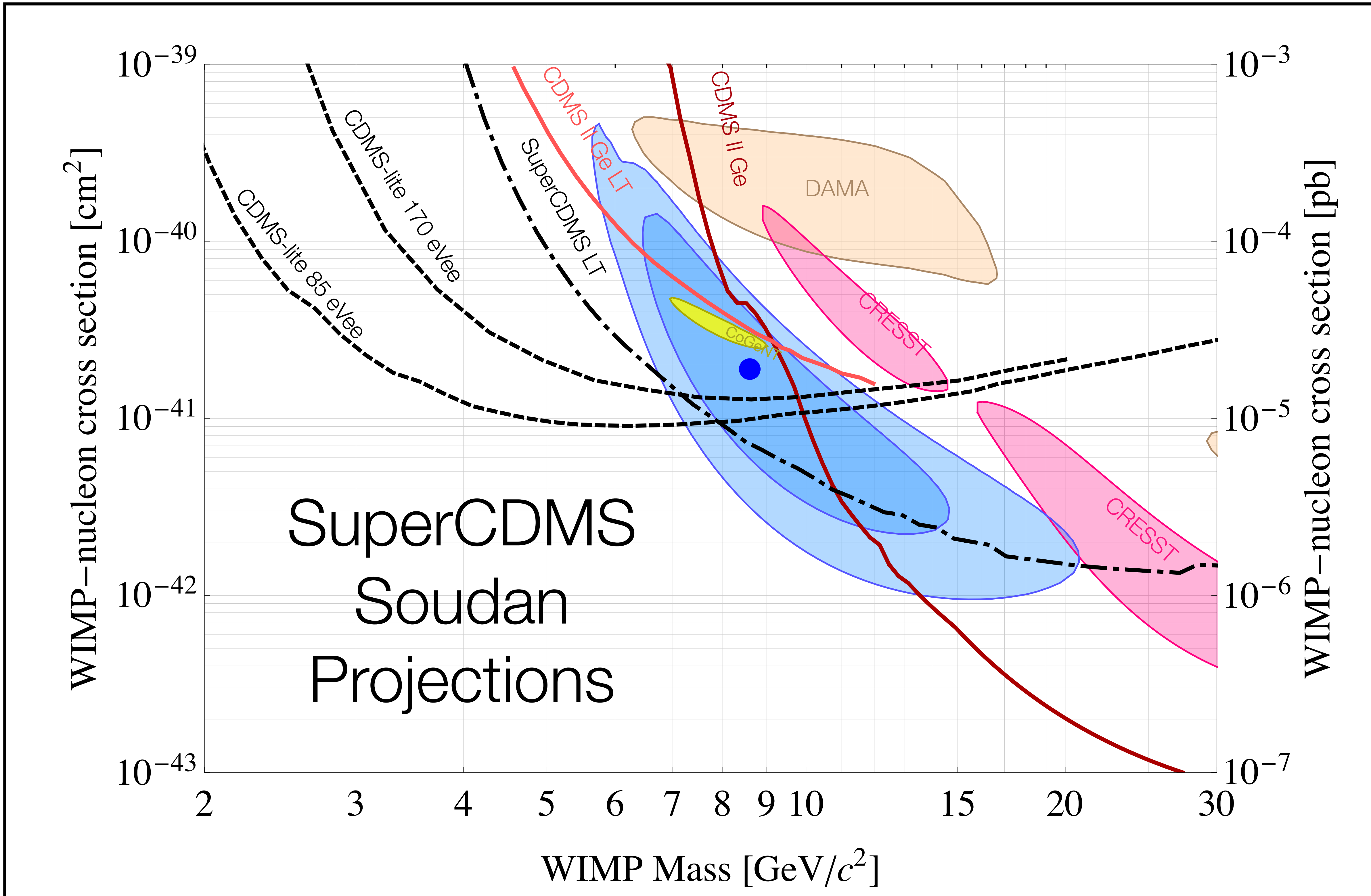




- 71,525 (38,178) electrons and 16,258 (7,007) ^{206}Pb recoil surface event collected from ^{210}Pb source in 905.5 (683.8) live hours
- In ~800 live hours 0 events leaking into the signal region (< 1.7 x 10^{-5} @90% C.L. misID)

- ~50% fiducial volume (8-115 keVr)
- <0.6 events in 0.3 ton-years
- Good enough for a 200 kg experiment run for 4 years at SNOLAB!

SuperCDMS @ Soudan: Low Mass Projections

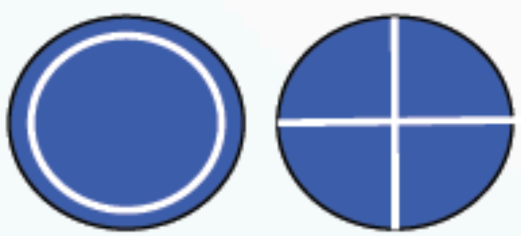


SNOLAB Detectors

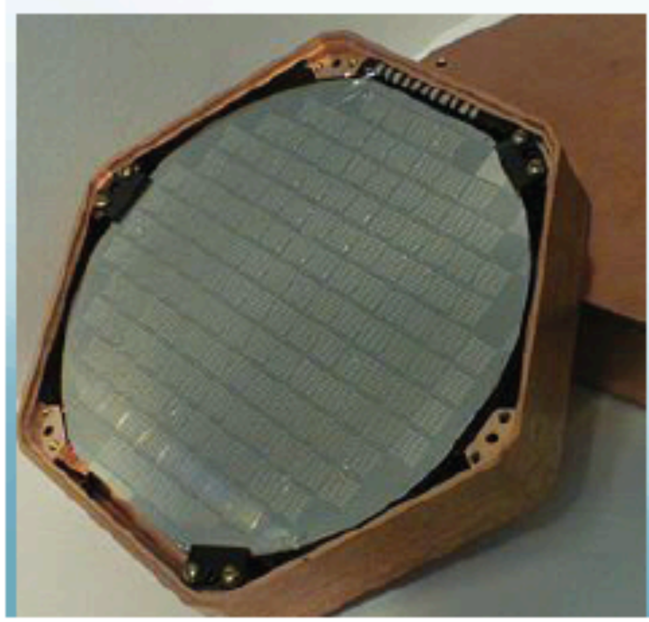
CDMS II

Single-sided
1 cm thick
3"diameter
250 g Ge

2 charge + 4 phonon



5 towers of 6 det each

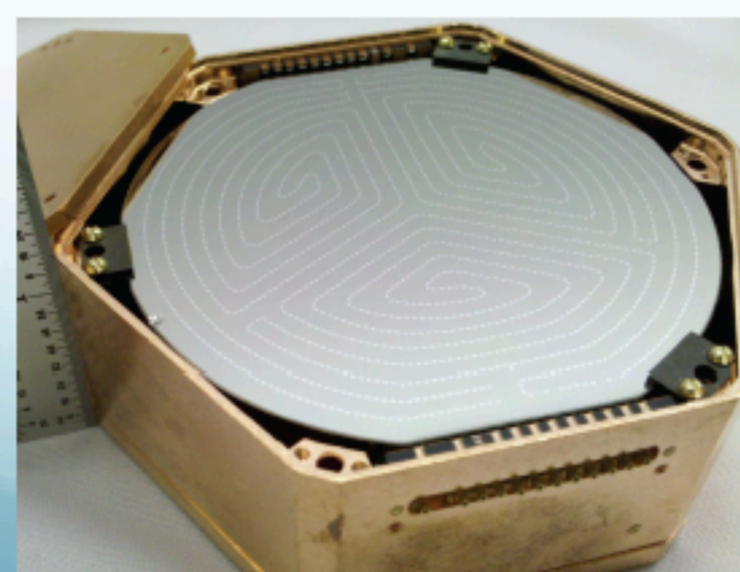


SuperCDMS Soudan

Double-sided
2.5 cm thick
3"diameter
620 g Ge

2 charge + 2 charge
4 phonon + 4 phonon

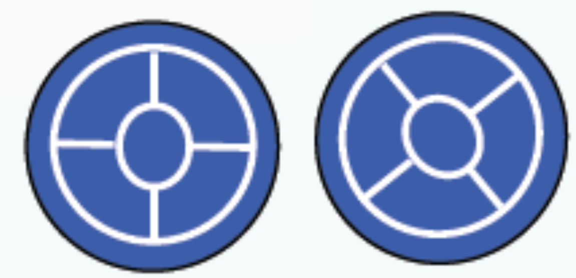
5 towers of 3 det each



SuperCDMS SNOLAB

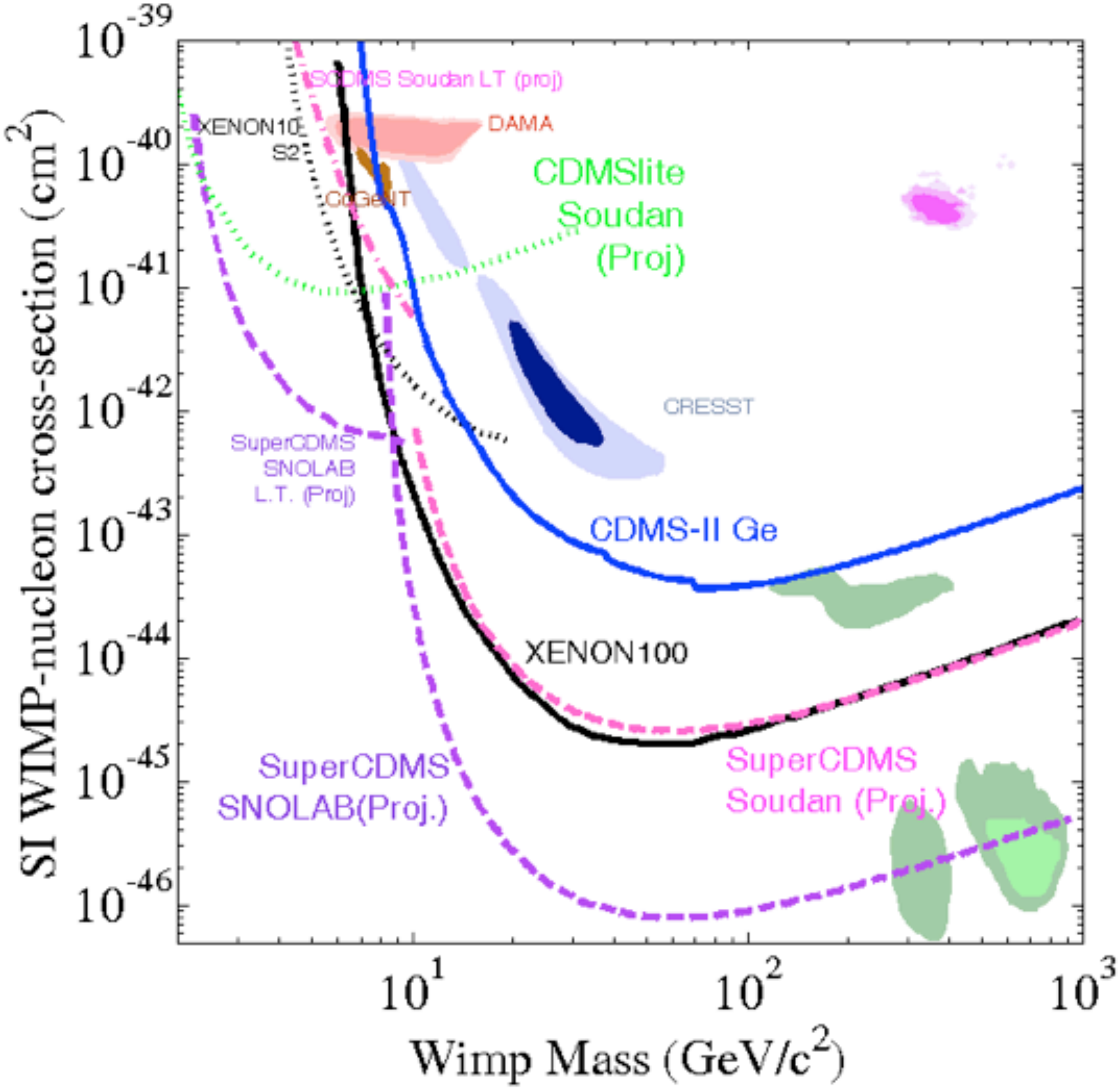
Double-sided
3.3 cm thick
4"diameter
1.38 kg Ge

2 charge + 2 charge
6 phonon + 6 phonon



24 towers of 6 det each

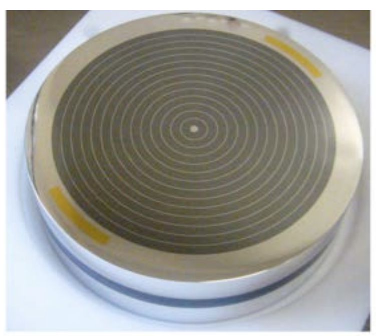
SNOLAB Projections

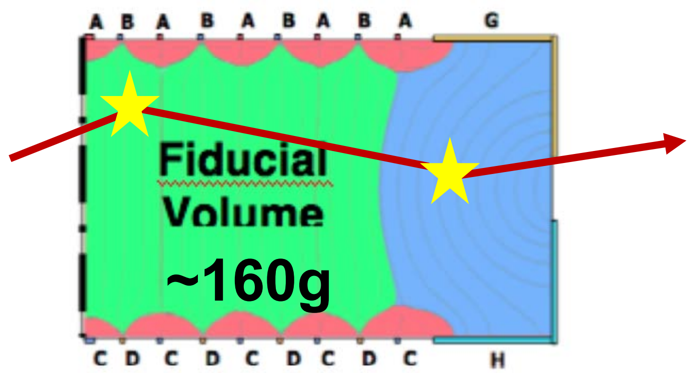


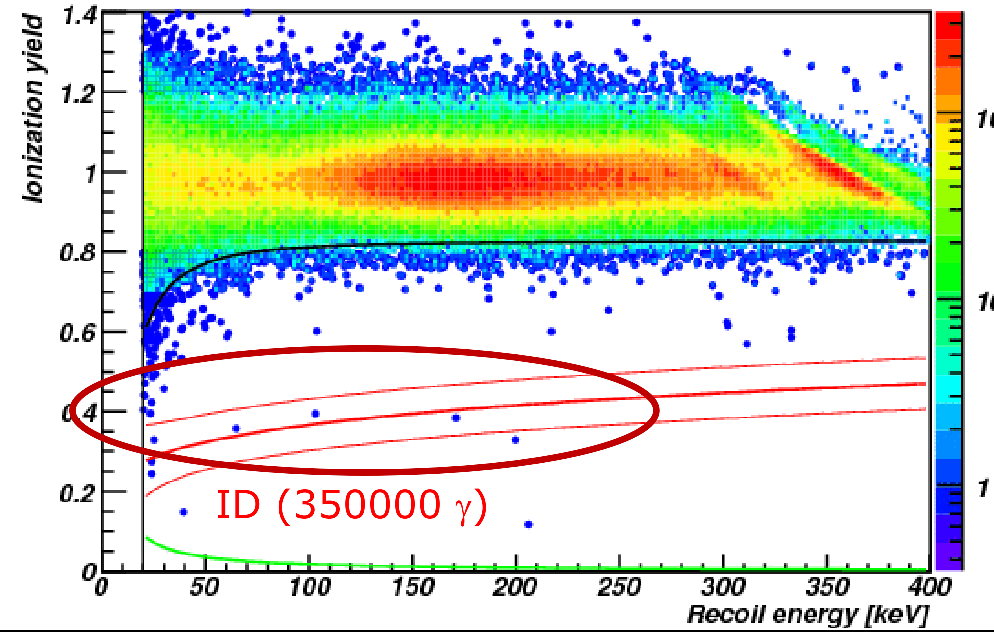
EDELWEISS

2. Improvement of γ discrimination

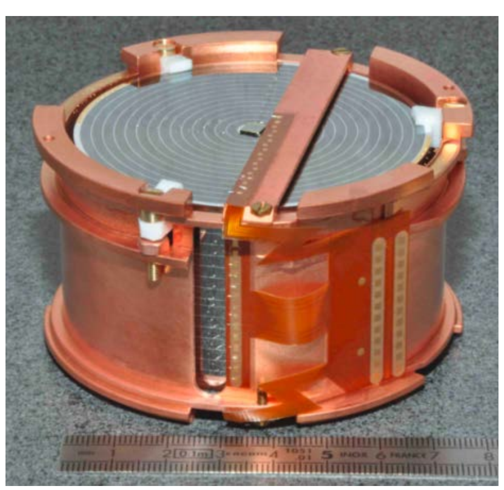
EDELWEISS-II
ID 400g with 10x **160g** fiducial mass

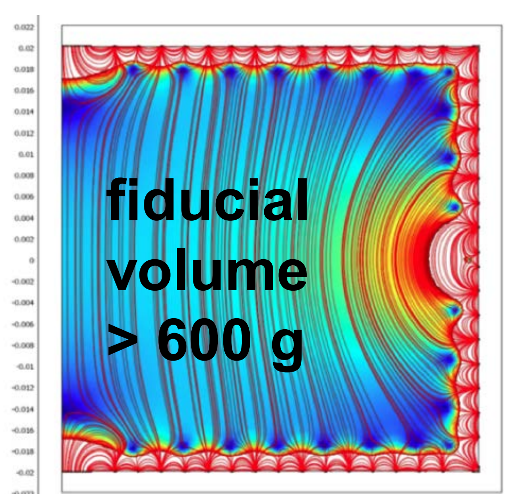


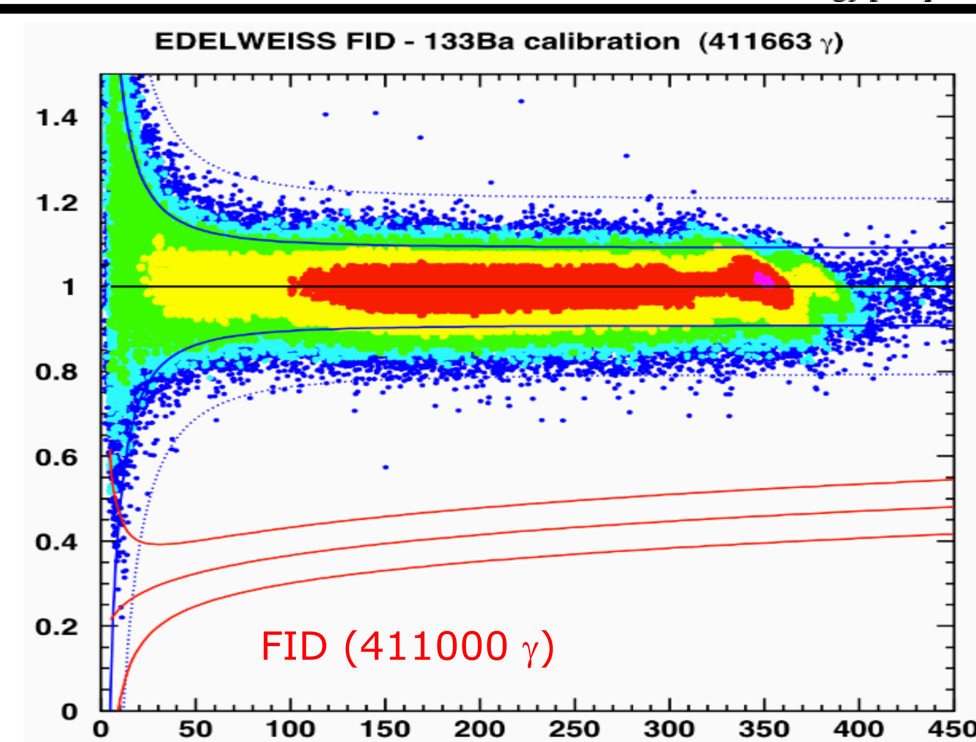




EDELWEISS-III
FID 800g with 40x **~600g** fiducial mass







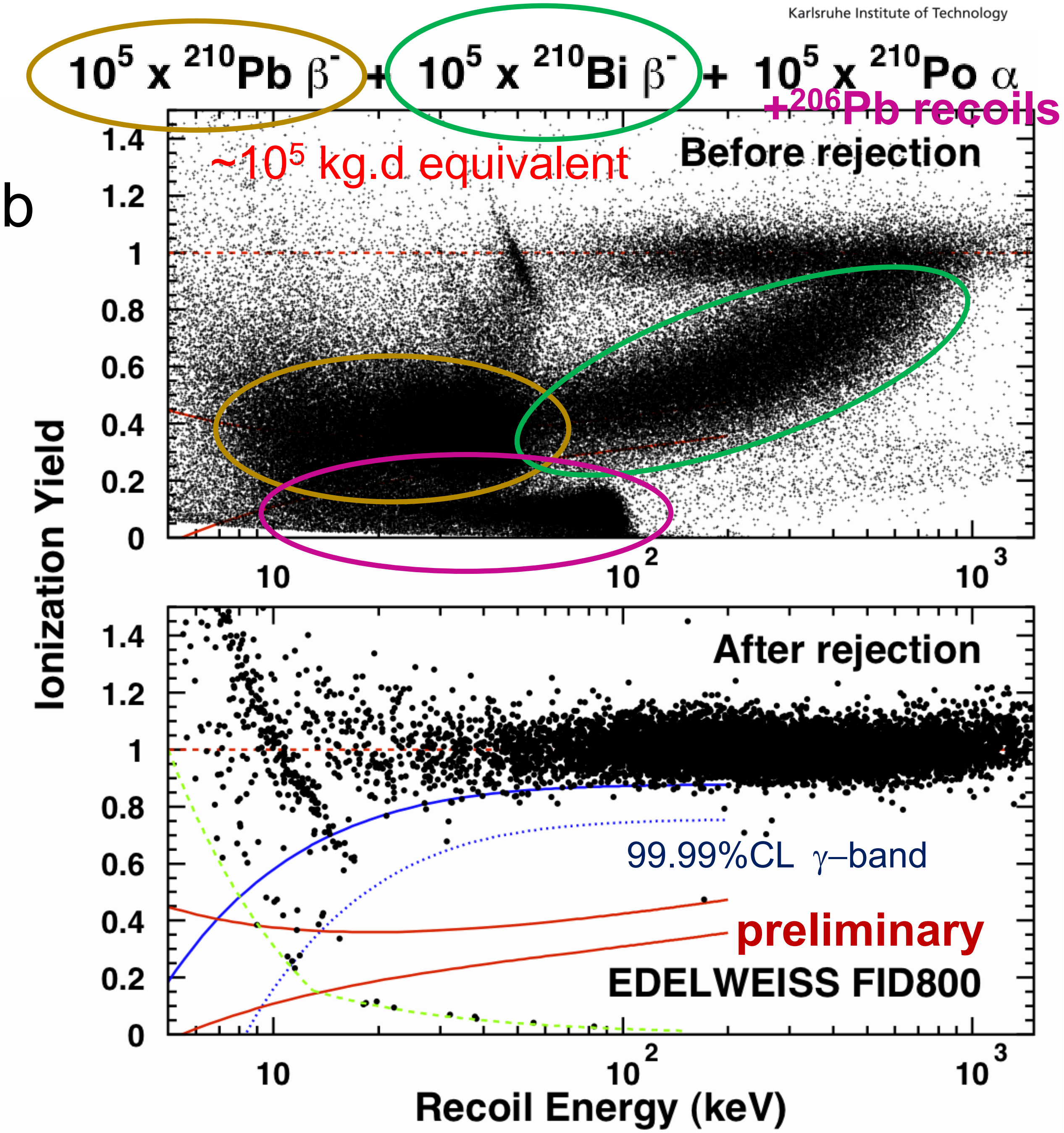
EDELWEISS

3. Surface rejection measurements – improved discrimination

- measurement with ^{210}Pb β-source
- surface rejection:
  < 4 x 10^{-5} misidentified events per kg.d (E_{rec}>15 keV)

better than previous EDELWEISS detectors

(< 6 x 10^{-5} misidentified events per kg.d, E_{rec}>20 keV)



CUORE

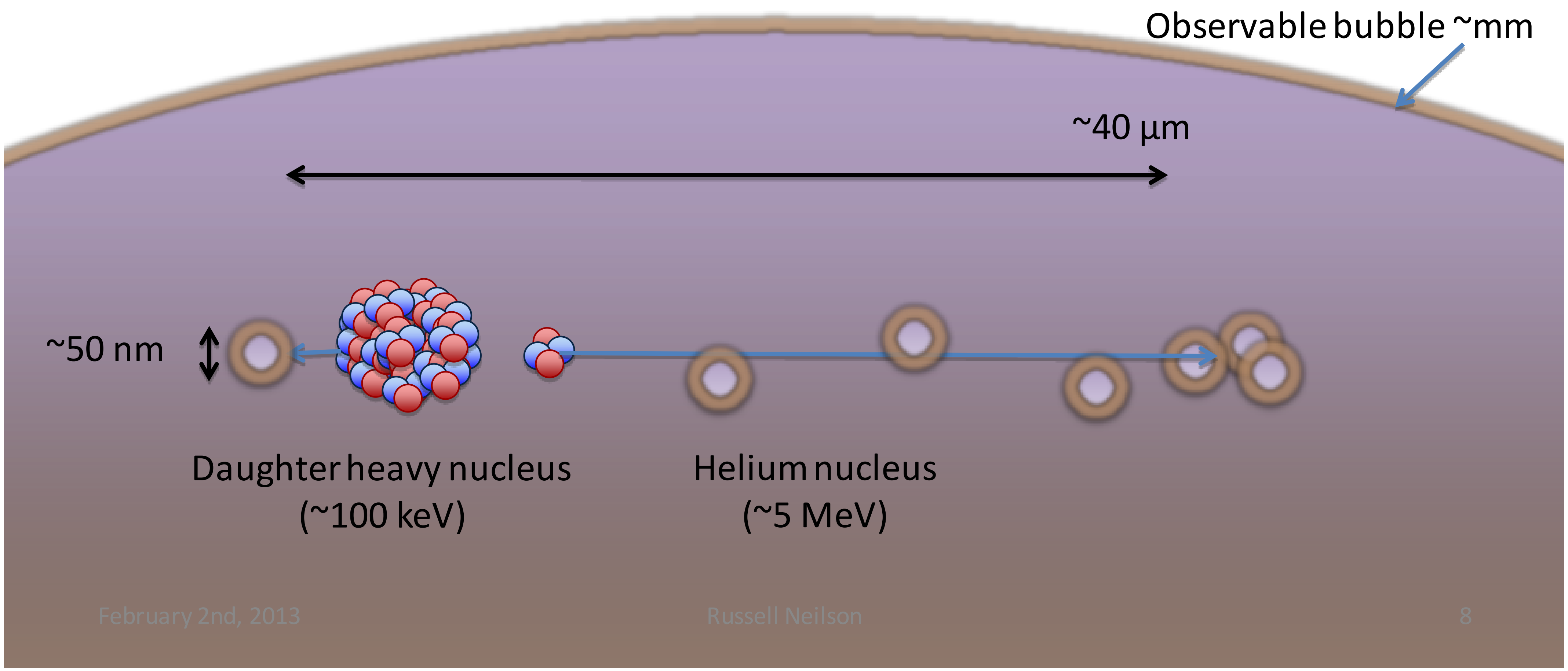
- Detection mechanism: coherent scattering of WIMP on detector nuclei
- Spin-dependent cross section highly suppressed, almost only spin-independent interactions
- Both heavy (Te) and light (O) targets in the same detector
- Scattered nucleus recoils in the crystal lattice, energy converted into heat

- PROS:
  - ✓ large mass, long term stability ==> seasonal modulation of events number
  - ✓ high energy resolution ==> seasonal modulation of spectral shape
  - ✓ quenching factor = 1, all energy detected for all recoils
  - ✓ detection efficiency =1, basically all recoils are fully contained
- CONS:
  - ✓ recoil energy is typically small (depending on nucleus and WIMP mass) ==> LOW THRESHOLD REQUIRED (<25keV)
  - ✓ no particle identification (nuclear recoils, gammas, betas, alfas all the same)

Great effort in lowering the threshold and reducing the background

COUPP

- Alphas deposit their energy over 10s of microns.
- Nuclear recoils deposit their energy over 10s of millimeters
- Alpha particles are louder than nuclear recoils. This can be measured by piezoelectric sensors.



DMTPC

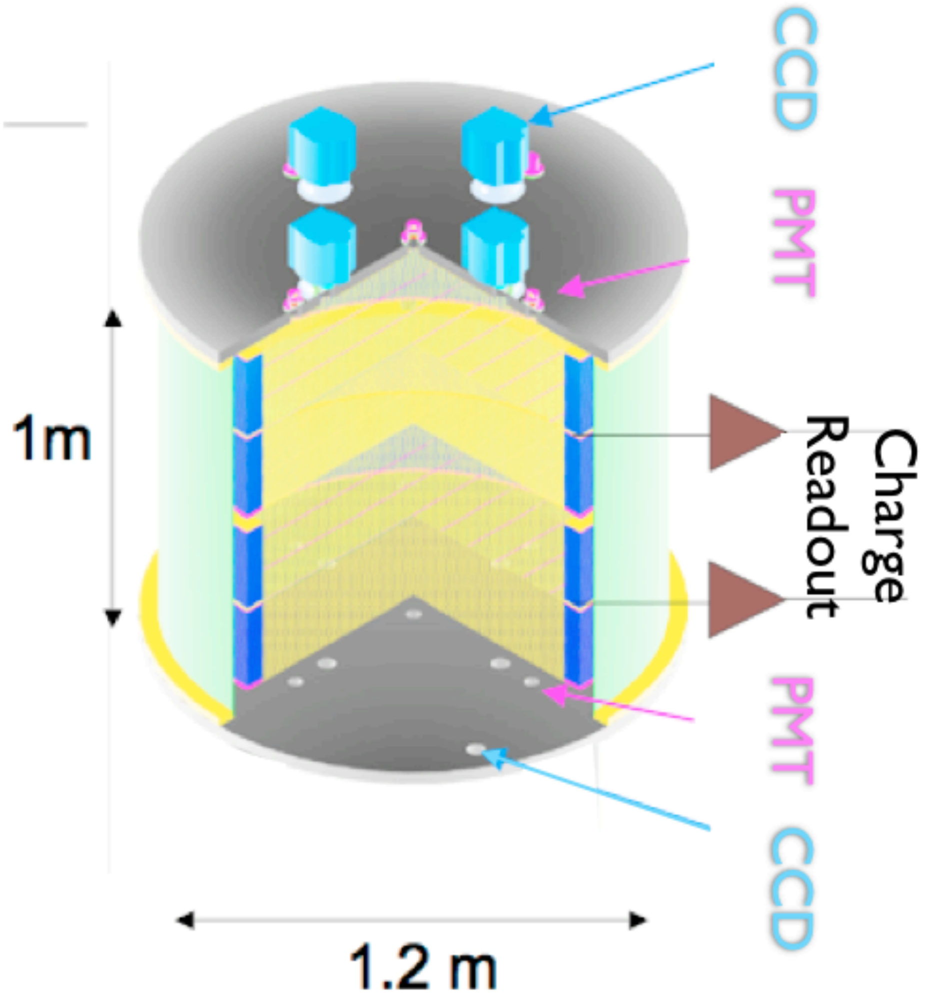
10L

Underground
at WIPP

4Shooter (20L)

At MIT

DMTPCino (1 m^3)



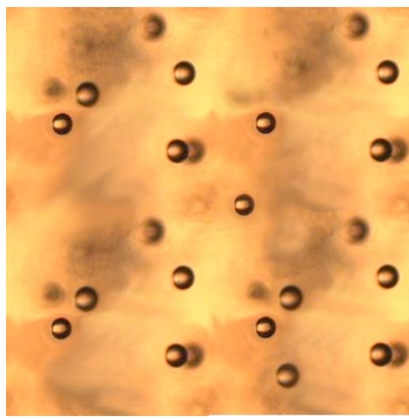
Funded by
NSF+DoE

James Battat   Bryn Mawr College

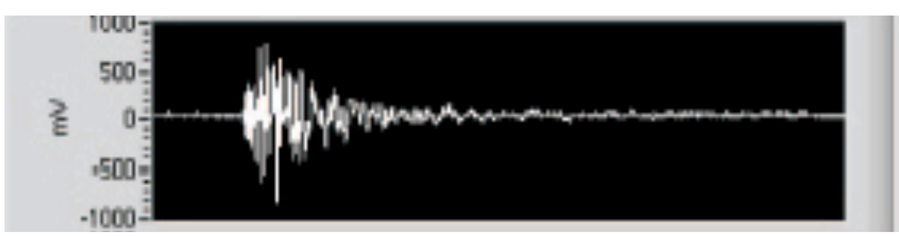
Jackson - Mon. DM II

PICASSO

- Modular detector (32 modules).
- Uses C_4F_{10} droplets (~200 µm diameter)…
- …suspended in polymerised aqueous gel matrix…



- …in 4.5L acrylic cylindrical container.
- 9 piezoelectric transducers record sound.



- 40-50 hr data taking runs.
- 2-5 hr calibration runs with neutron source.
- 11 hr recompression between runs.