SuperCDMS and EURECA search for WIMPs : recent results and status of projects at SNOLAB

Introduction

Cryogenic detectors

SuperCDMS LT and HV

EURECA in Europe

Plans at SNOLAB

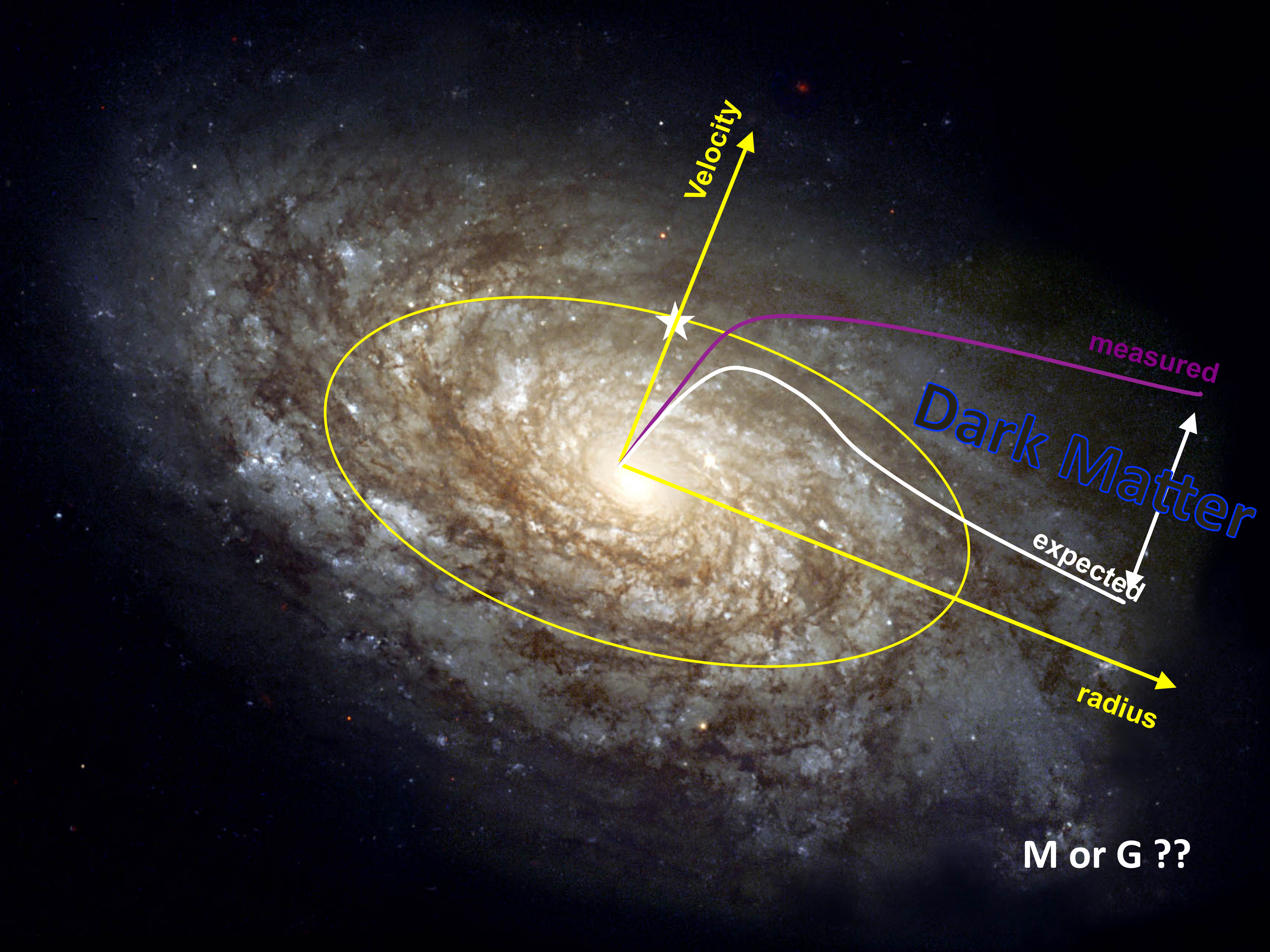
Gilles Gerbier

Queen's University

Lake Louise Winter Institute 2015 – fev18th

Canada Excellence Research Chairs

Chaires d'excellence en recherche du Canada

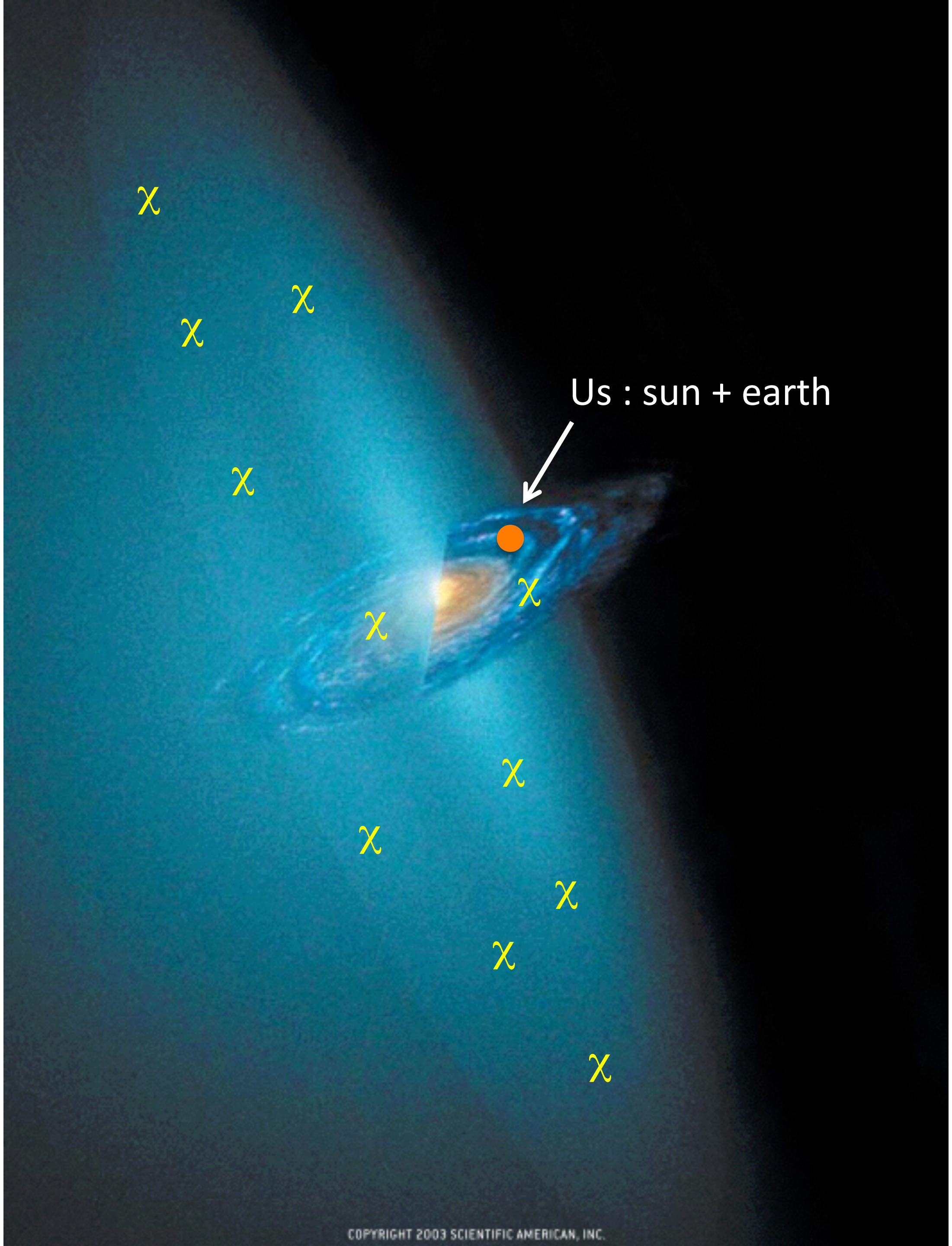


Velocity
measured
Dark Matter
expected
radius
M or G ??

The picture

Our
own Galaxy
the Milky Way
is
embedded
in a halo of
dark matter
made of
« new » particles
- relative to the
ones we know and
love : electrons
protons neutrons
neutrinos -
= WIMP's or χ

Can we
« see »
or
detect
them ?



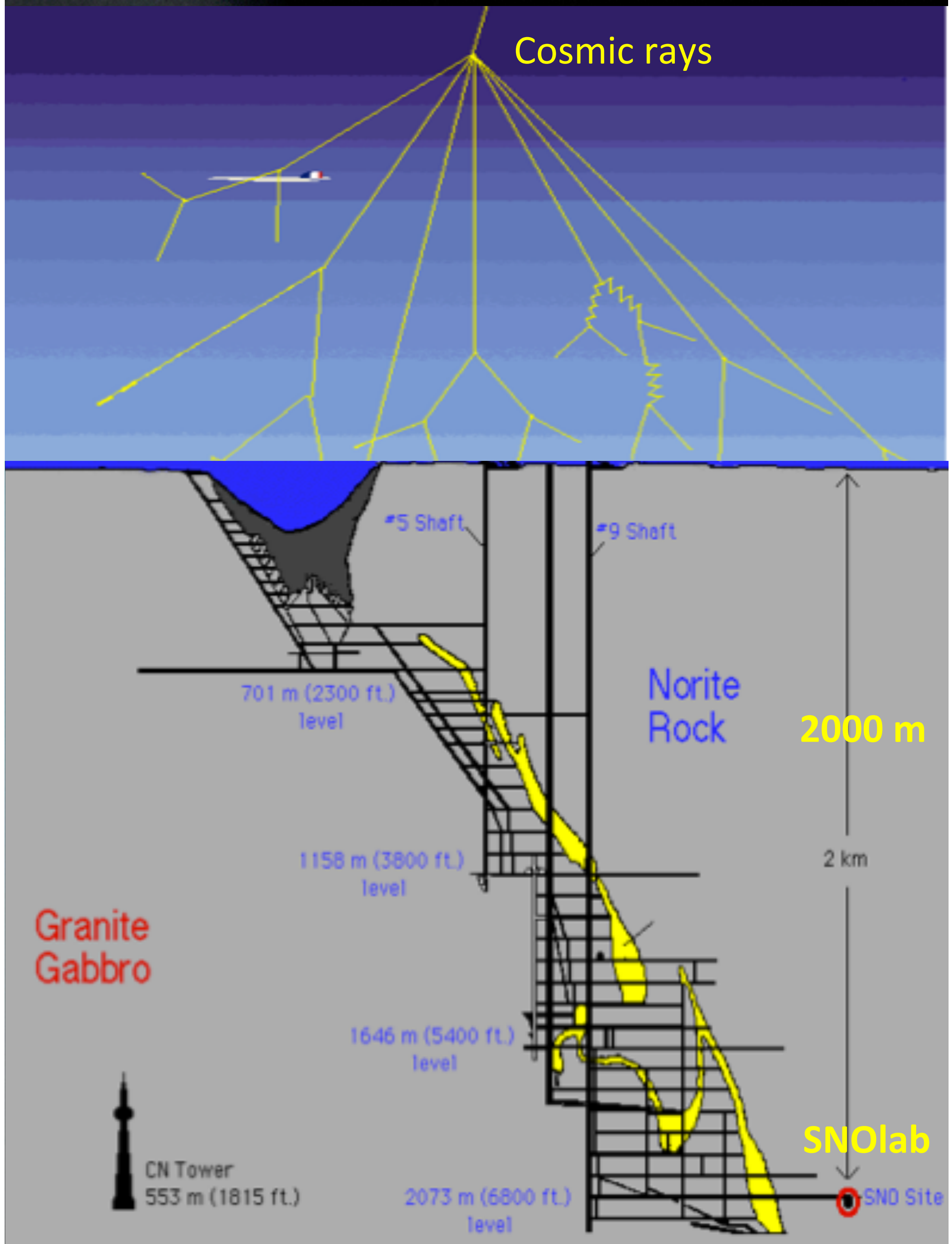
Yes we can

Tiny
and rare
impacts on
matter
=>
Go
underground
to avoid
« background »
from known
particles
like
cosmic rays in
sensitive
detectors

The picture

Our own Galaxy the Milky Way is embedded in a halo of dark matter made of « new » particles - relative to the ones we know and love : electrons protons neutrons neutrinos - = WIMP's or χ

Can we « see » or detect them ?

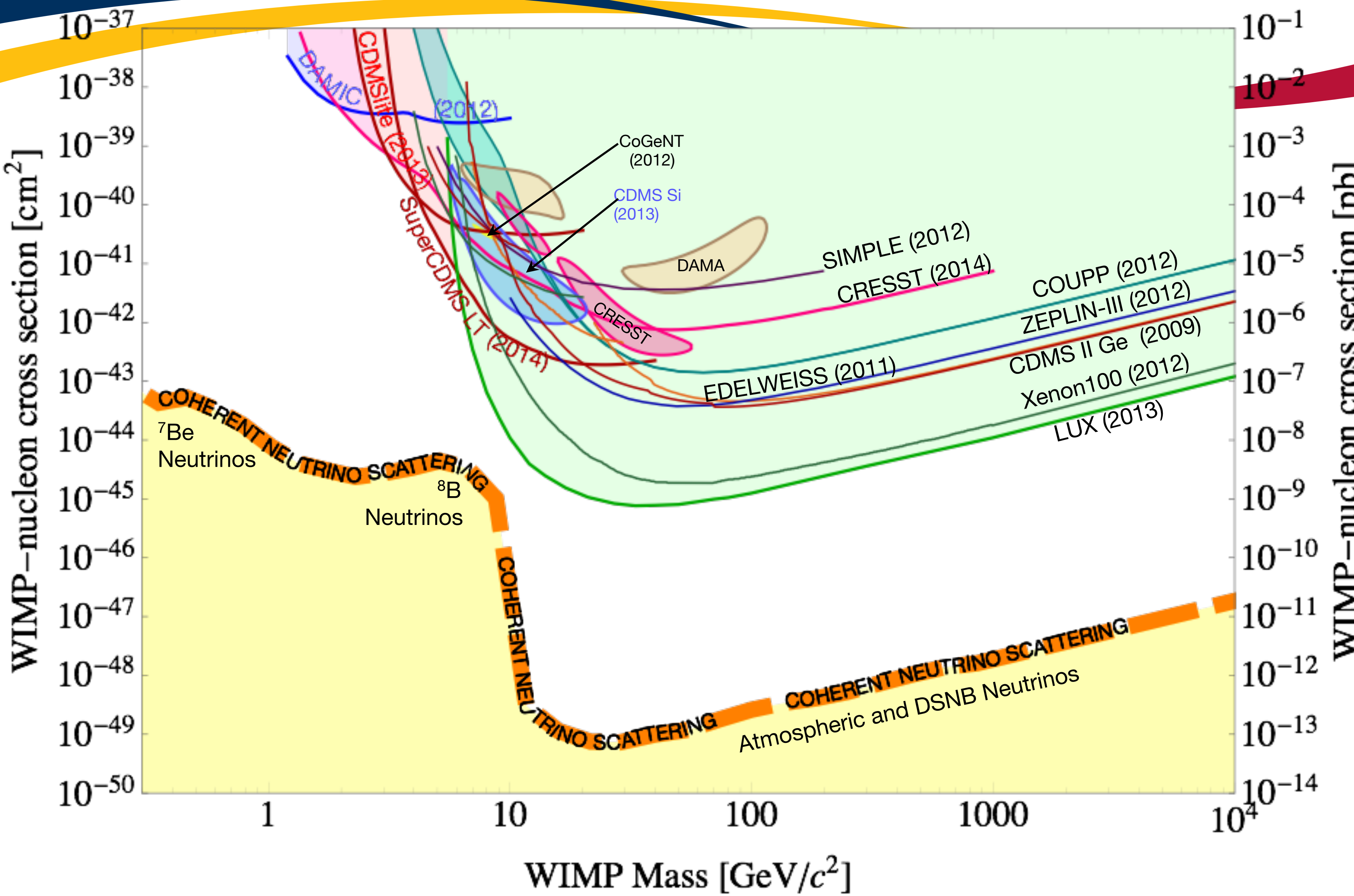


Yes we can

Tiny and rare impacts on matter => Go **underground** to avoid « background » from known particles like cosmic rays in sensitive detectors

Best worldwide is **SNOLab Ontario**

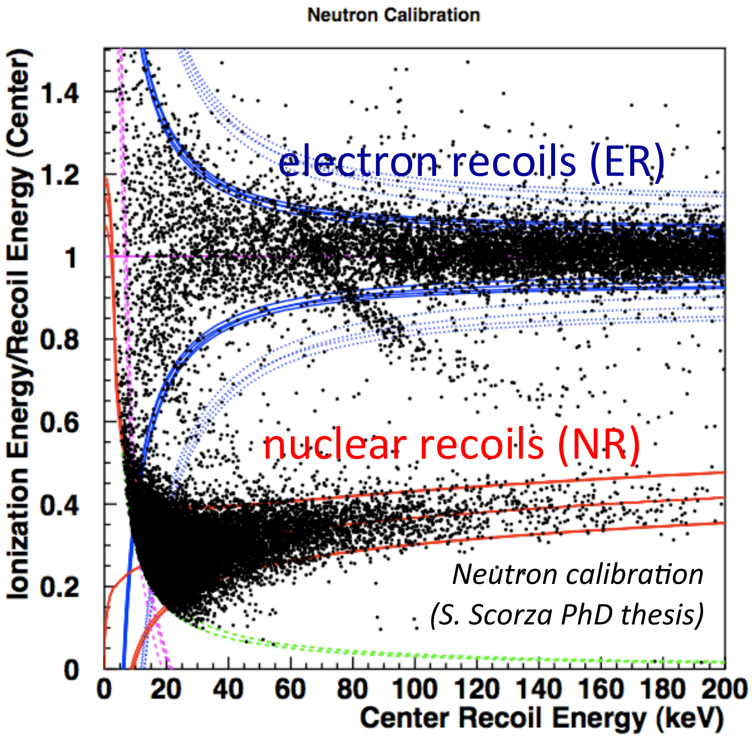
Direct detection, SI, status at sept 2014

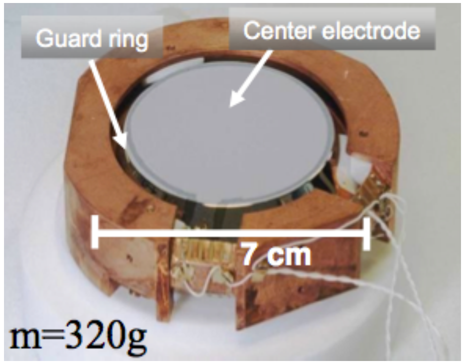


Spin Independent couplings

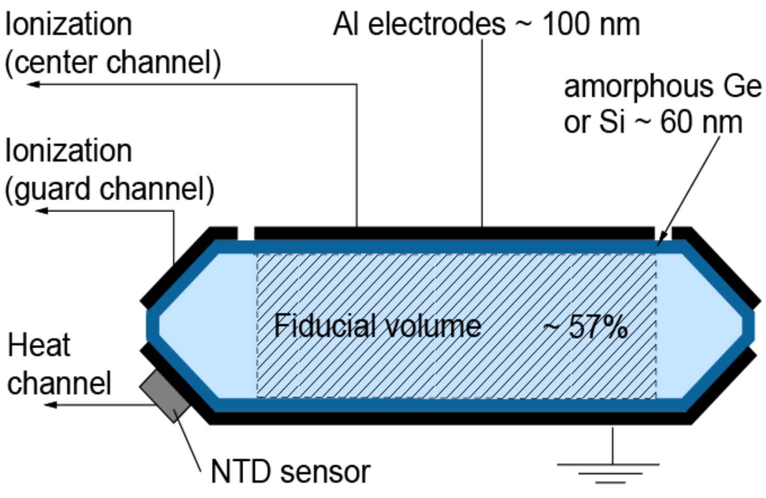
Ge cryogenic detector : 3 parameters to isolate signal
Example of Edelweiss detectors

- Germanium bolometers
- **Ionization** measurement @ few V/cm
- **Heat** measurement (**NTD sensor**), 20 mK
- Discriminating variable between ER and NR
  « Q » = ionization/recoil energy





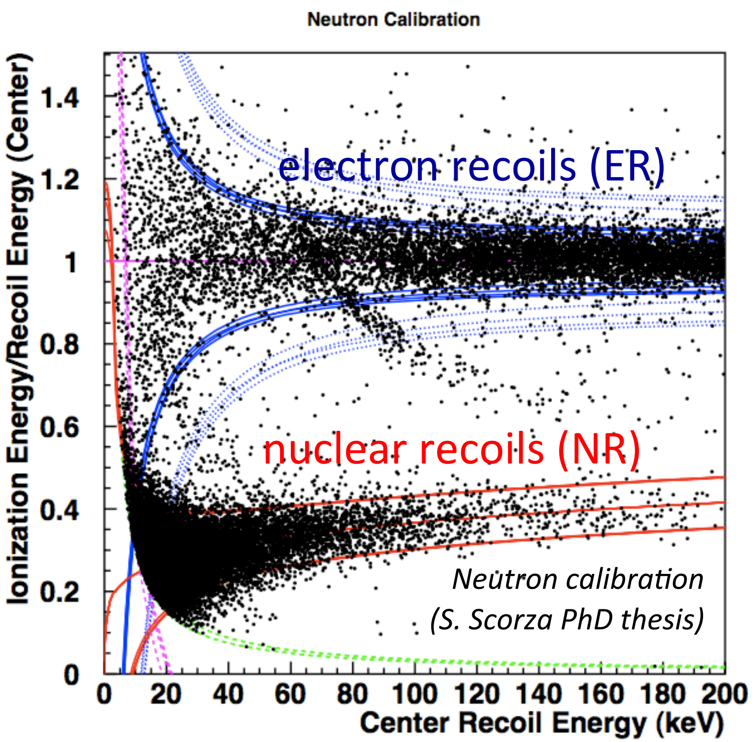
All planar electrode

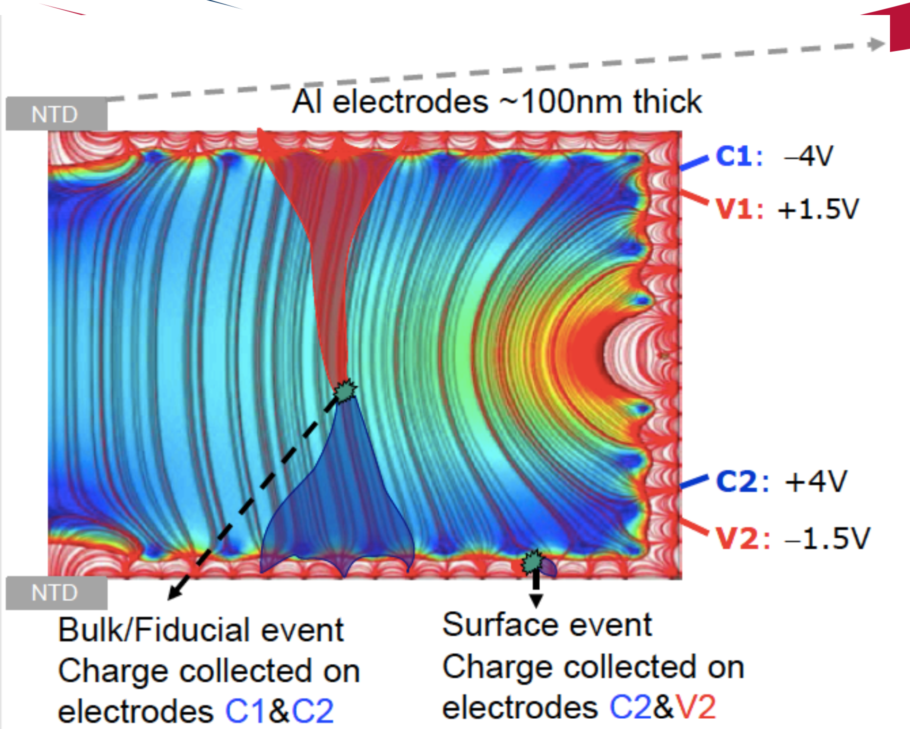


Old 300 g Ge planar electrodes

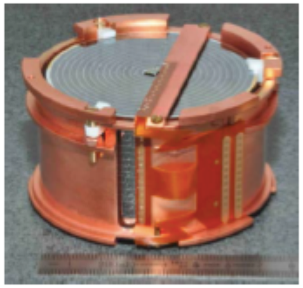
Ge cryogenic detector : 3 parameters to isolate signal
Example of Edelweiss detectors

- Germanium bolometers
- **Ionization** measurement @ few V/cm
- **Heat** measurement (**NTD sensor**), 20 mK
- Discriminating variable between ER and NR
  « Q » = ionization/recoil energy





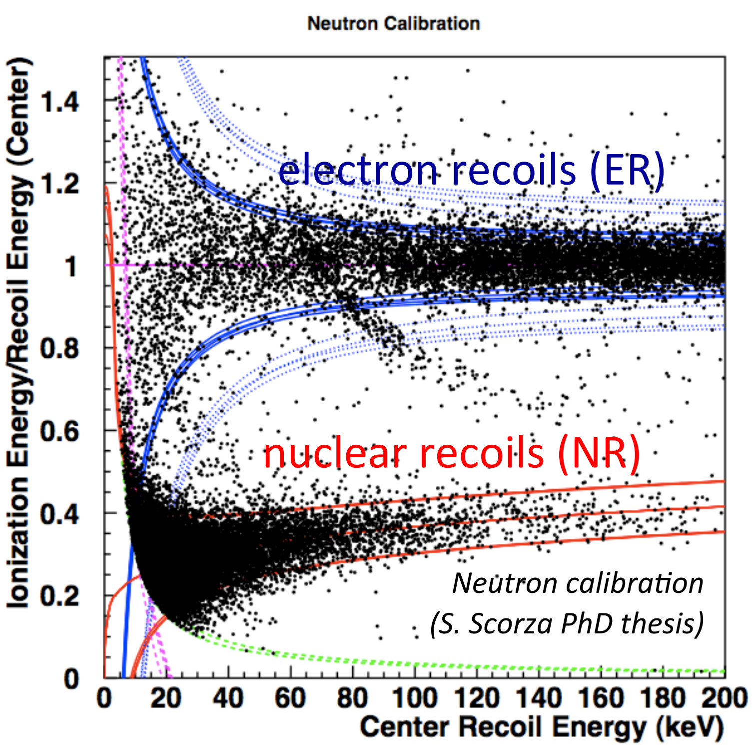
800 g FID800 actual detectors

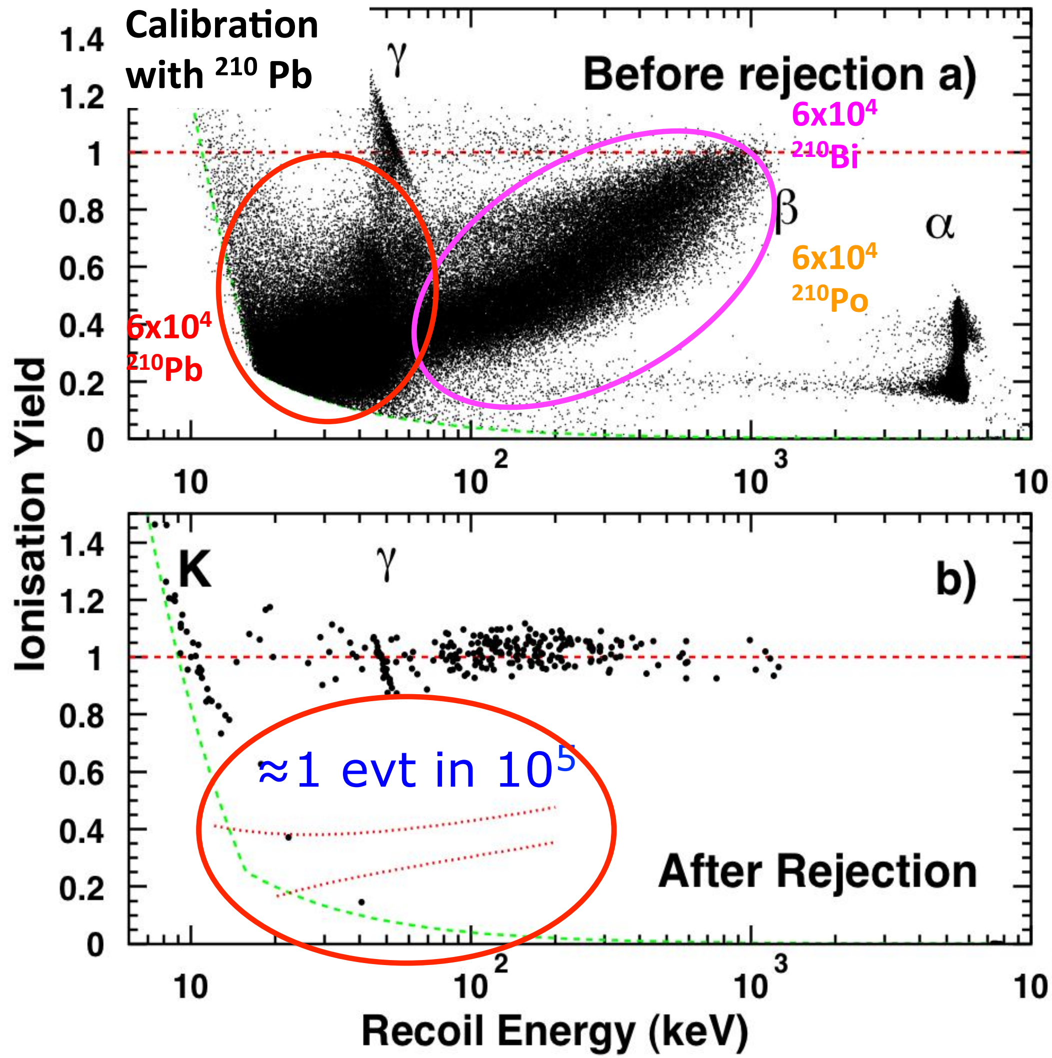


- = **Ionization « VETO » = >** « Surface/beta » identification : if non zero, reject event

Ge cryogenic detector : 3 parameters to isolate signal
Example of Edelweiss detectors

- Germanium bolometers
- **Ionization** measurement @ few V/cm
- **Heat** measurement (**NTD sensor**), 20 mK
- Discriminating variable between ER and
  « Q » = ionization/recoil energy





■ = **Ionization « VETO » = >** « Surface/beta » identification : if non zero, reject event

The SuperCDMS Collaboration

California Inst. of Tech.
B. Cornell, S.R. Golwala, R.H. Nelson

CNRS-LPN
Q. Dong, A. Cavanna, U. Gennser, L. Couraud, Y. Jin

FNAL
R. Basu Thakur , D.A. Bauer, D. Holmgren, L. Hsu, B. Loer

Mass. Inst. of Tech.
A.J. Anderson, J. Billard, E. Figueroa-Feliciano, A. Leder, K.A. McCarthy

NIST Inst. of Tech.
J. Ullom

PNNL
J. Hall

Queen's University
C.H. Crewdson, P.C.F. Di Stefano, O. Kamaev, P. Nadeau, K. Page, W. Rau, Y. Ricci

Santa Clara University
B.A. Young

SLAC
M. Asai, A. Borgland, D. Brandt, P.L. Brink, G.L. Godfrey, M.H. Kelsey, R. Partridge, K. Schneck, D.H. Wright

Southern Methodist U.
R. Calkins, J. Cooley, B. Kara, H. Qiu, S. Scorza

Stanford University
B. Cabrera, D.O. Caldwell*, R.A. Moffatt, P. Redl, B. Shank, S. Yellin, J.J. Yen

Syracuse University
M.A. Bowles, R. Bunker, Y. Chen, R.W. Schnee

Texas A&M University
H.R. Harris, A. Jastram, R. Mahapatra, J.D. Morales Mendoza, K. Prasad, D. Toback, S. Upadhyayula, J.S. Wilson, S. Yeager

U. Autónoma de Madrid
D.G. Cerdeno, L. Esteban, E. Lopez Asamar

U. British Columbia
S.M. Oser, W.A. Page, H.A. Tanaka

U. California, Berkeley
M. Daal, T. Doughty, N. Mirabolfathi, A. Phipps, M. Pyle, B. Sadoulet, B. Serfass, D. Speller

U. Colorado Denver
M.E. Huber

U. Evansville
A. Reisetter

U. Florida
R. Agnese, D. Balakishiyeva, T. Saab, B. Welliver

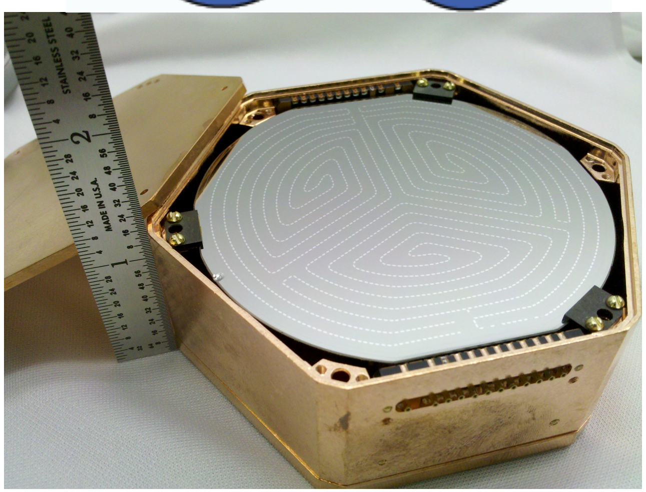
U. Minnesota
D. Barker, H. Chagani, P. Cushman, S. Fallows, T. Hofer, A. Kennedy, K. Koch, V. Mandic, M. Pepin, H. Rogers, A.N. Villano, J. Zhang

U. South Dakota
J. Sander

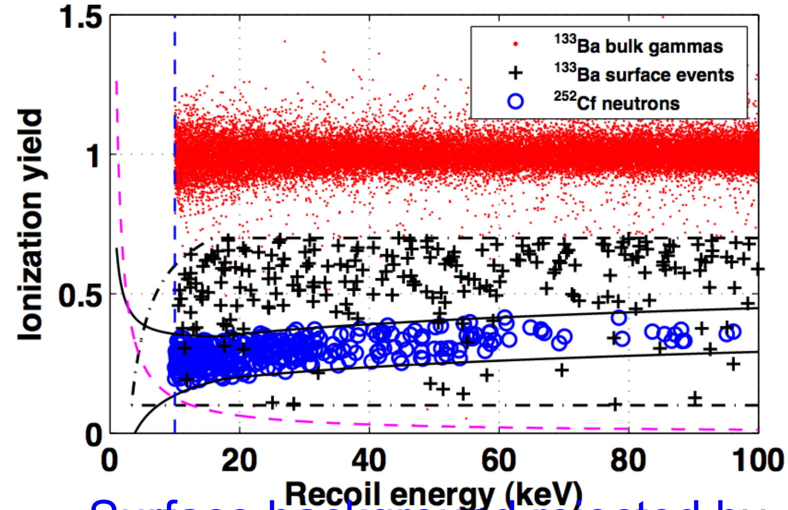
*Emeritus Professor at U.C. Santa Barbara

SuperCDMS Soudan Detectors

- 15 detectors deployed
- 600 g Ge each
- Operated at ~60 mK
- 2 x (2 charge + 4 phonon) readout

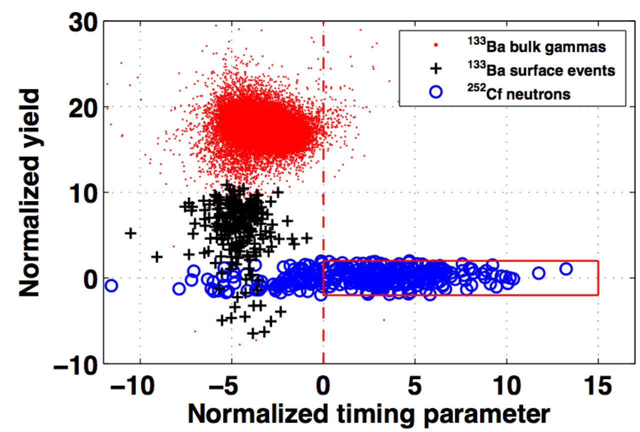


- Ionization yield → rejection of bulk background



(CDMS II)

- Surface background rejected by
  - Radial position
  - Timing of phonon signal



(CDMS II)

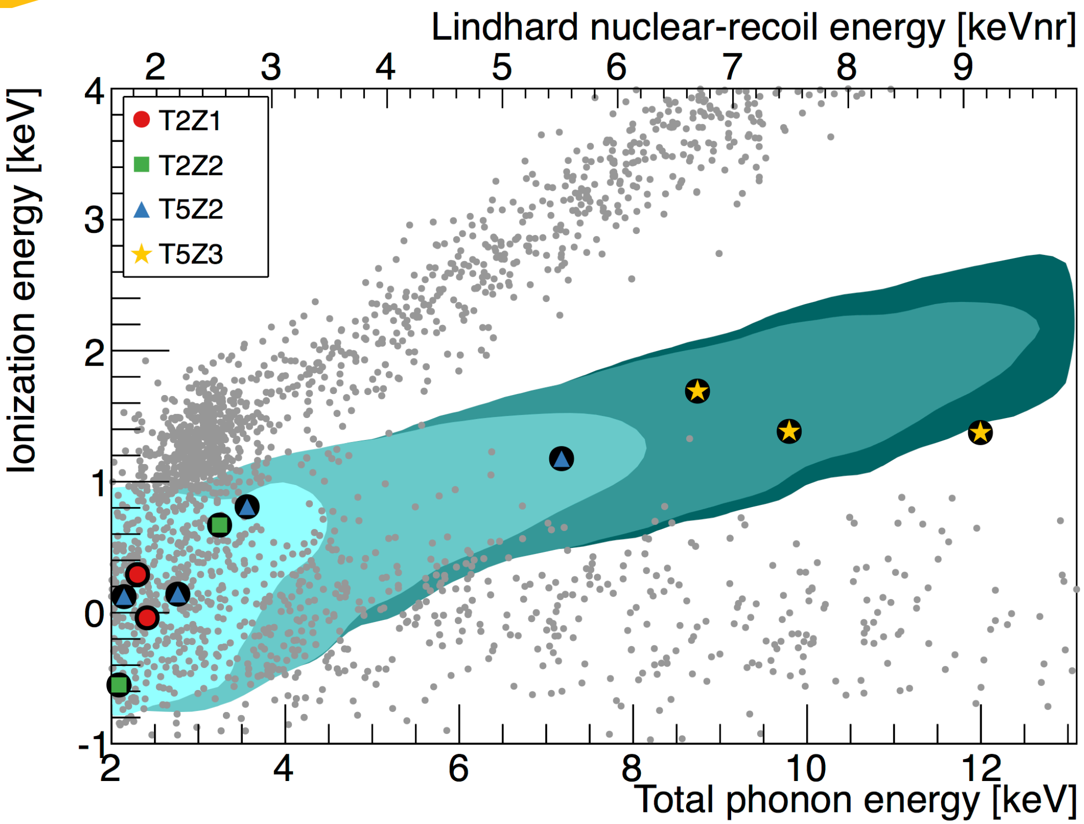
  - Added : interleaved electrodes (iZIPs), cf EDW

Low-threshold blind analysis

- **Select high quality data**
- **Simulate backgrounds**
  - ^{210}Pb decay chain on detector, housing
  - External gammas from shielding and cryostat
  - Internal activation lines from cosmics and thermal neutron capture
  - Cosmogenic and radiogenic neutron background (small contribution)

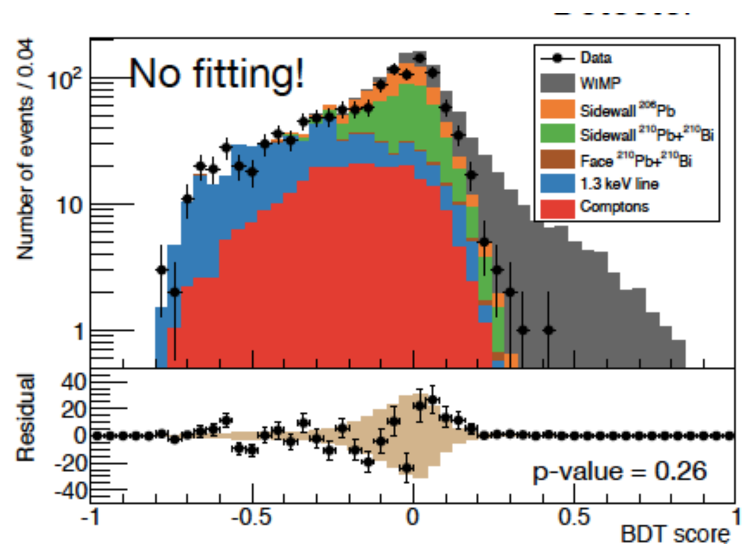
- **Optimize Discrimination** for various WIMP masses using a **boosted decision tree**
  - Parameters : phonon energy, ionization, phonon radial partition, phonon z partition
  - Trained on:
    - Simulated background
    - Neutron data weighted to represent WIMP spectra at various masses

Low-threshold unblinded results



95% confidence contours for expected signal from 5, 7, 10 & 15 GeV/c^2 WIMPs

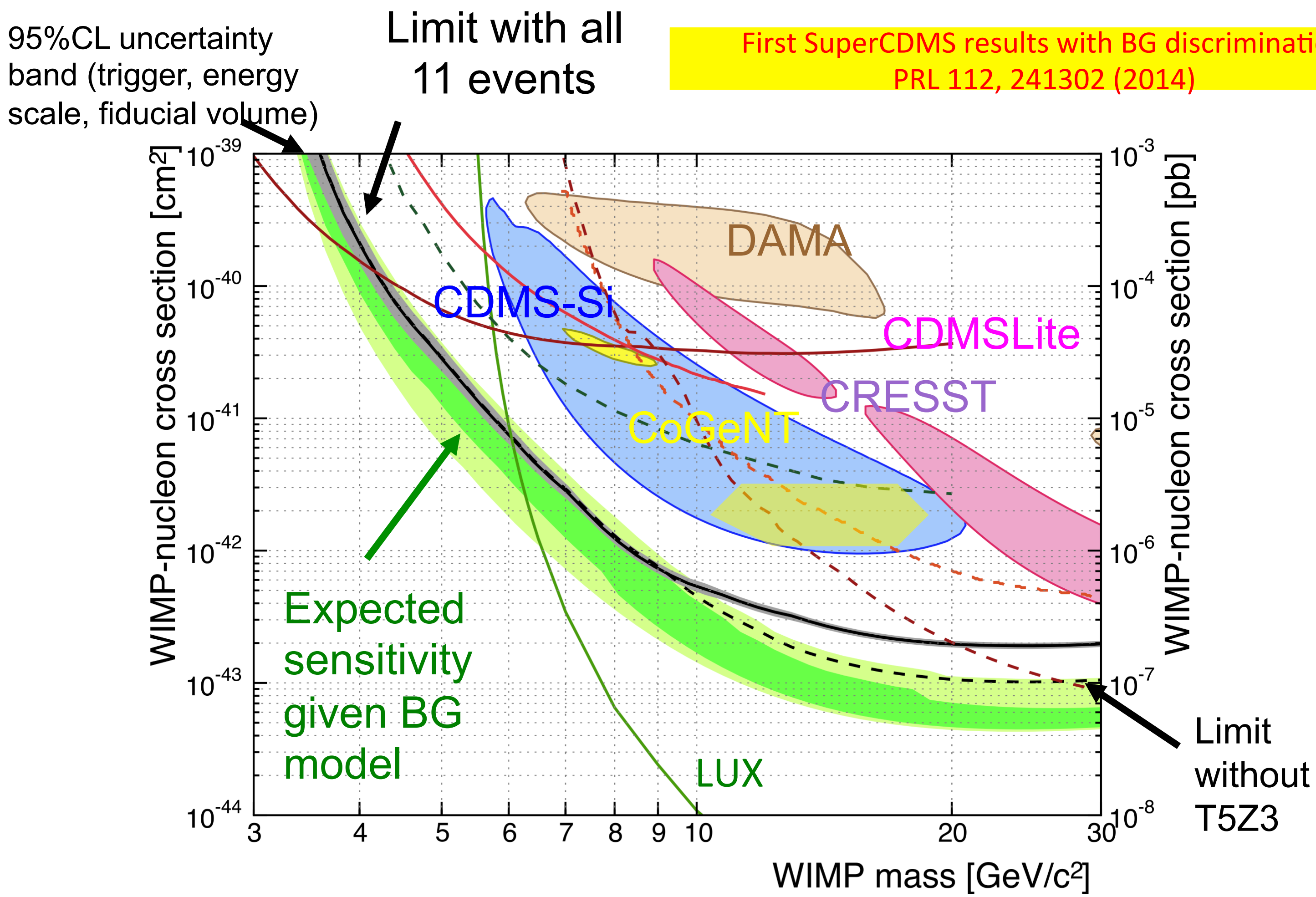
- $6.1^{+1.1}_{-0.8}$ evts expected
- 11 observed, including 3 at high energy from T5Z3 (with malfunctioning guard electrode)



SuperCDMS low-threshold results

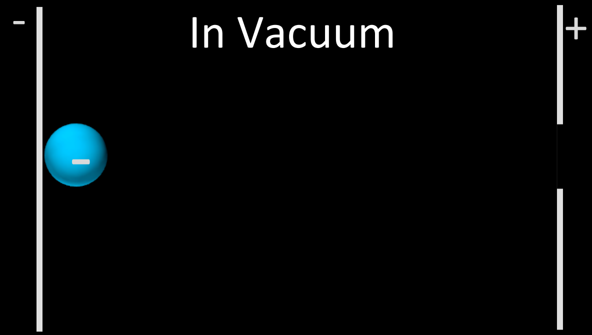
- 90%CL upper limits set using optimal interval technique

First SuperCDMS results with BG discrimination
PRL 112, 241302 (2014)

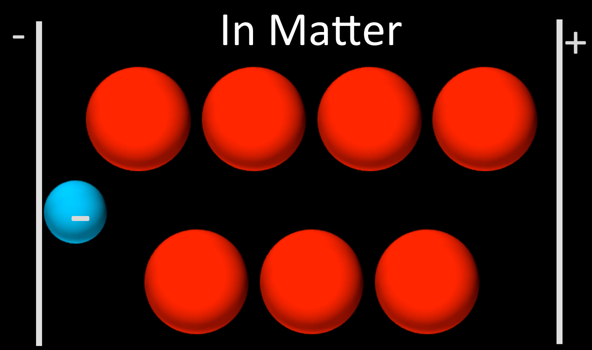


- Strong tension with all WIMP claims…

CDMSlite ; Other running mode of Ge detectors : enhancing Neganov-Luke Phonons by HV between electrodes



Electron gains kinetic energy
($E = q \cdot V \rightarrow 1\ eV$ for 1 V potential)



Deposited energy in crystal lattice:
Neganov-Luke phonons

$\propto$ V, # charges

- Luke phonons mix charge and phonon signal → reduced discrimination
- Apply high voltage → large final phonon signal, measures charge!!
- ER much more amplified than NR
  → gain in threshold; dilute background from ER

Courtesy of Wolfgang Rau

Luke-Neganov effect in CDMSLite:
Use phonons to read charge

- Bias a standard SuperCDMS 600 g iZIP detector at 69 V (rather than 4 V)
- Phonon amplification proportional to charge, bias voltage (**CDMSLite: x24 for gammas**)

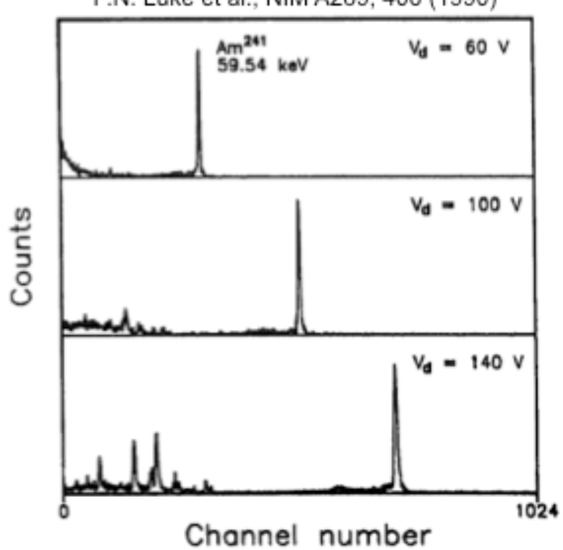
Exposure 6.3 kg.d

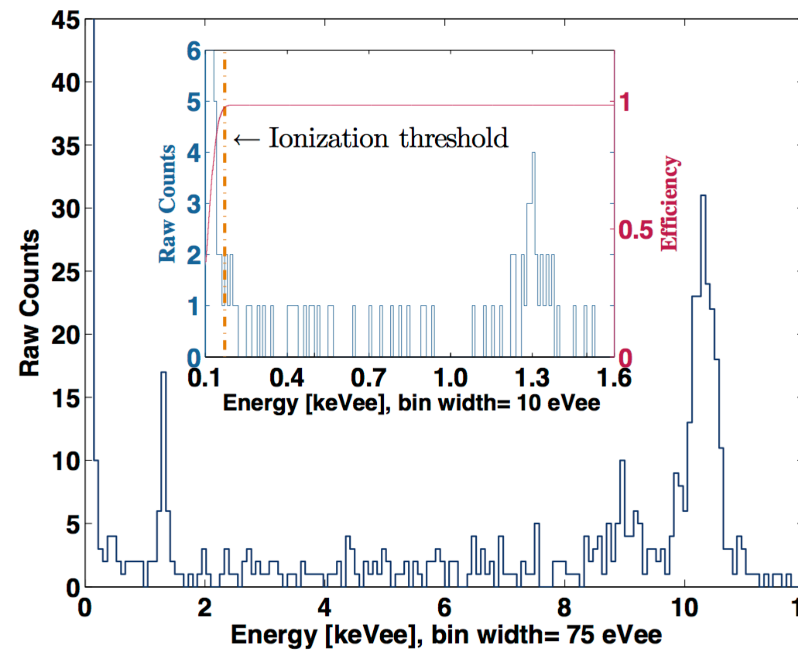
Excellent threshold (170 eVee ie 840 eVnr on Ge), resolution (1σ 43 eVee @ 1.3 keVee)

Loss of background discrimination

BG diluted with respect to signal

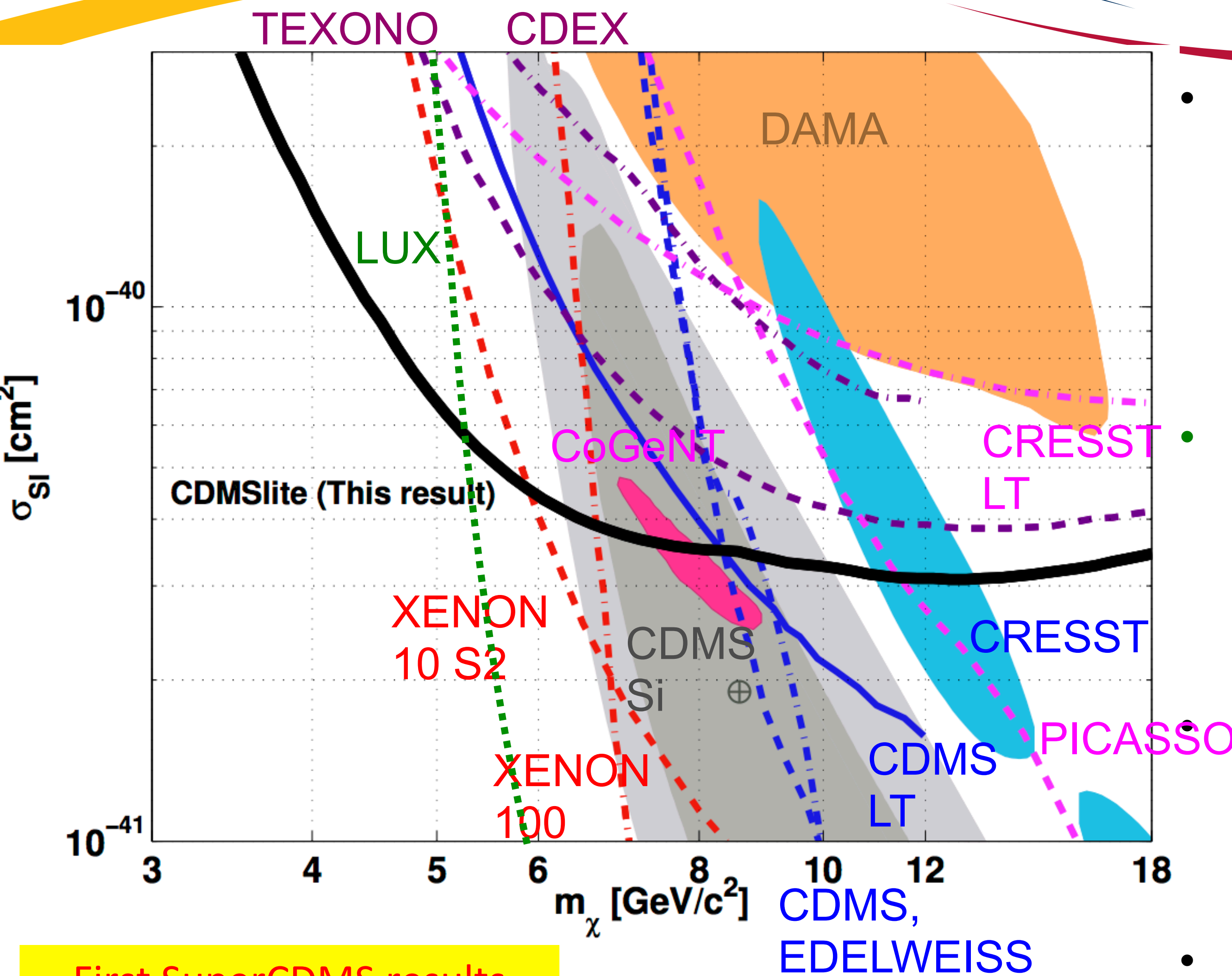
P.N. Luke et al., NIM A289, 406 (1990)





(n activation → K and L shell captures of ^{71}Ge visible)

CDMSLite first result

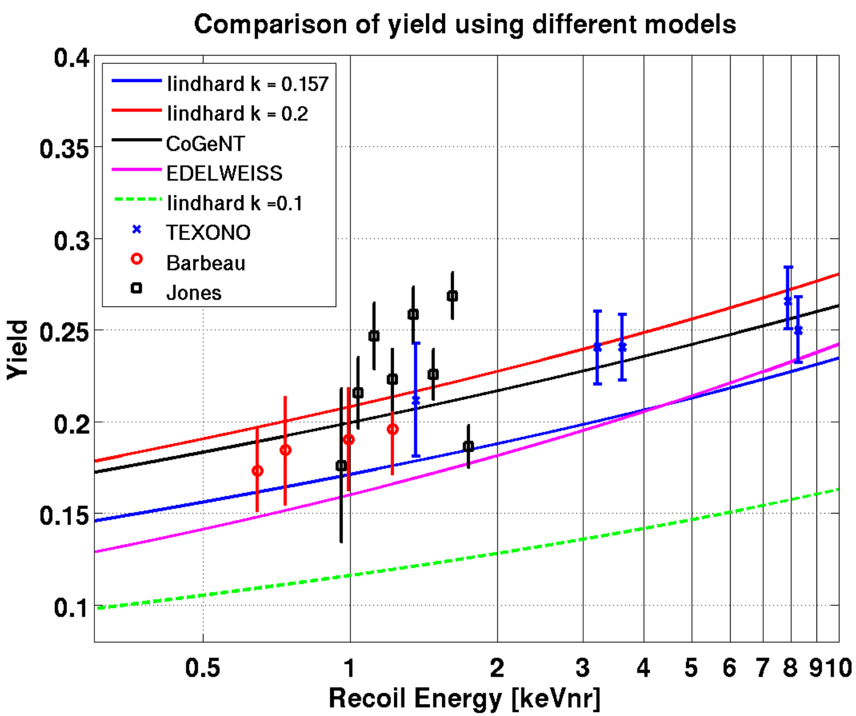


First SuperCDMS results
PRL 112, 041302 (2014)

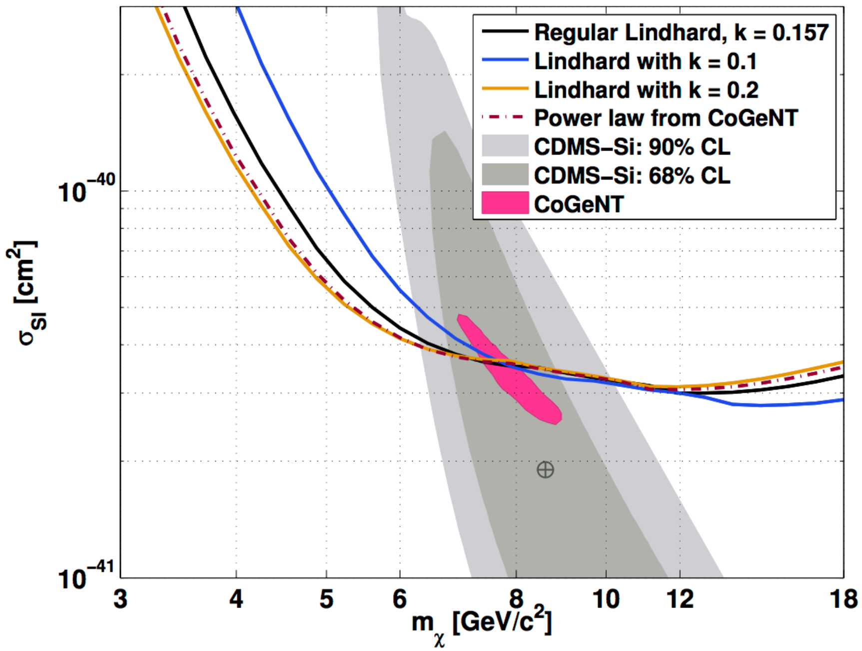
- Despite small exposure (6 kg.d), CDMSLite set new constraints **<6 GeV** thanks to excellent threshold
- CDMSLite will increase exposure to better understand backgrounds
- Now, some SuperCDMS detectors being operated in this mode
- NB : QF to be known accurately

CDMSLite : Quenching, an important input

- Need to transform energy scale calibrated with electron recoils to nuclear recoils
- Experiments in literature use different electrical fields, temperature → chose standard Lindhard model (cf Barker & Mei)

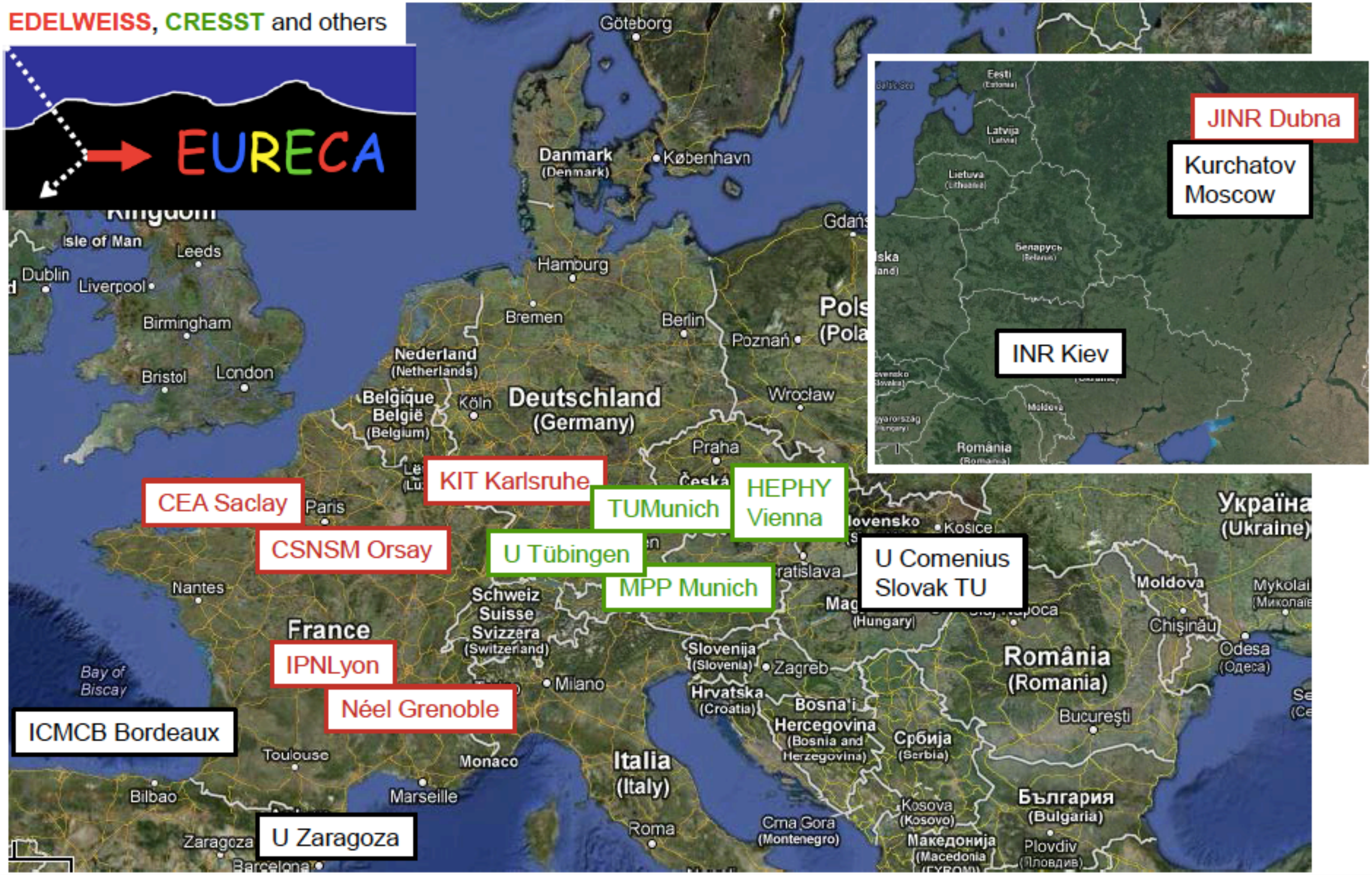


- Affects limits mainly beneath 7 GeV



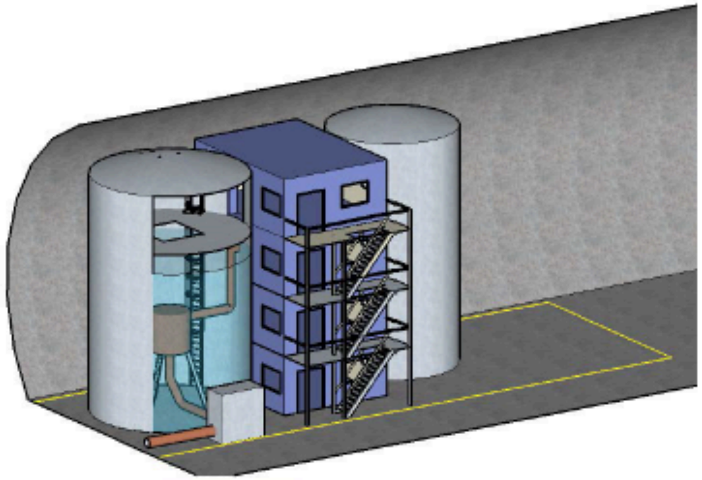
EURECA collaboration

EDELWEISS, CRESST and others

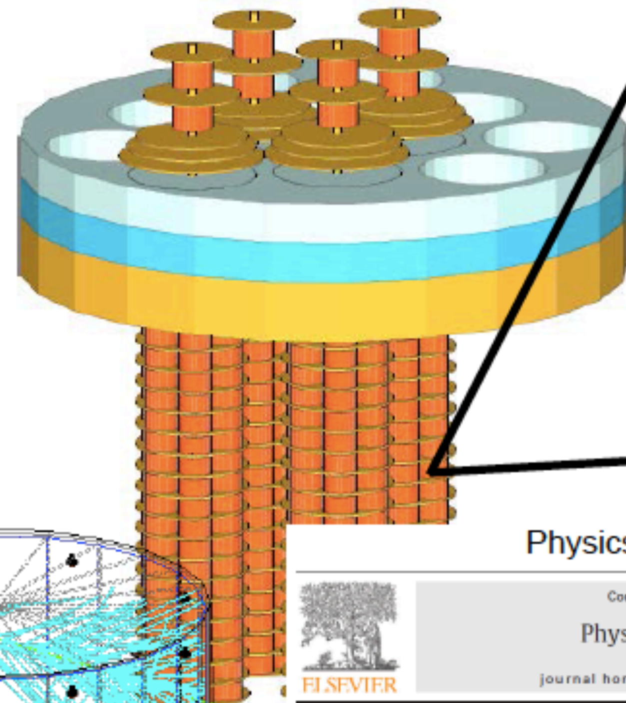


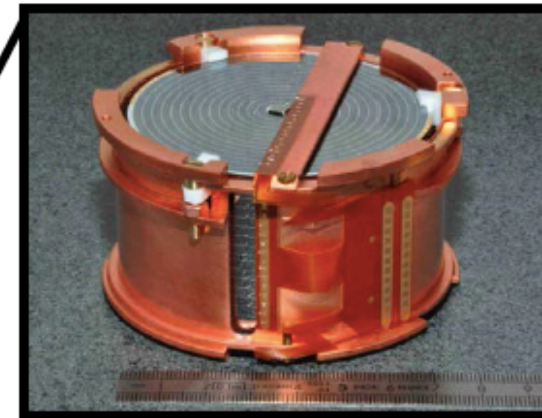
EURECA

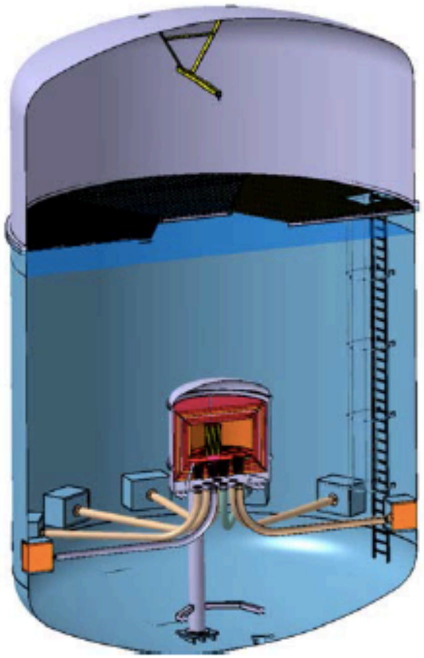
Initial goal (2012)

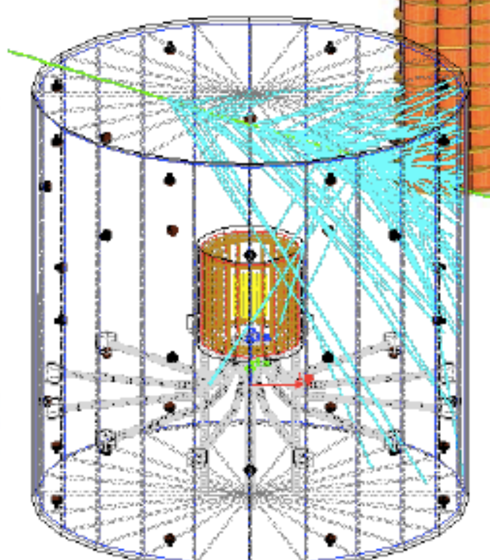


EURECA 1ton-stage









Physics of the Dark Universe 3 (2014) 41–74

ELSEVIER

Contents lists available at ScienceDirect

Physics of the Dark Universe

journal homepage: www.elsevier.com/locate/dark

EUREKA Conceptual Design Report

CrossMark

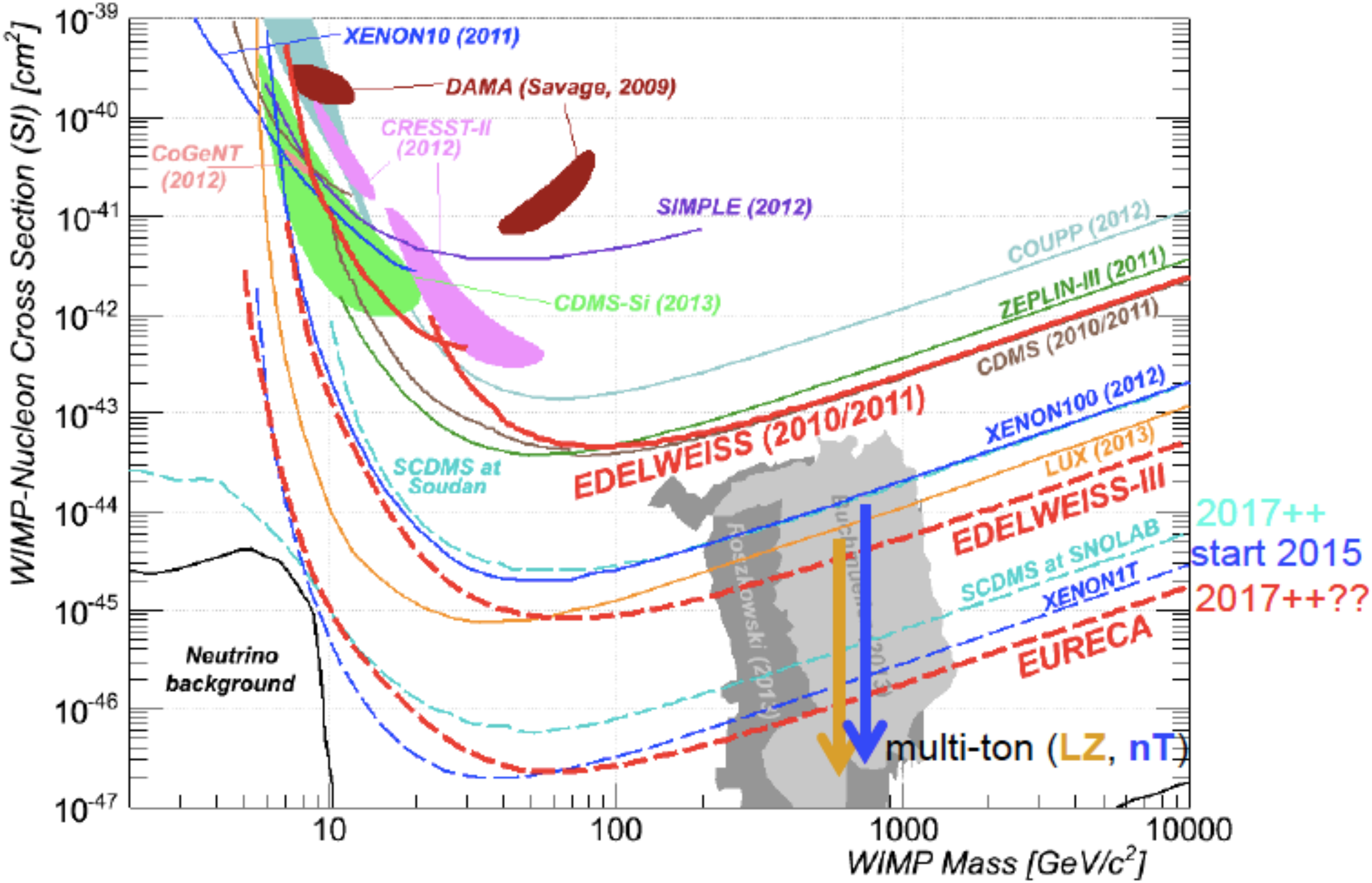
The EURECA Collaboration

G. Angloher[n], E. Armengaud[b], C. Augier[g], A. Benoit[f], T. Bergmann[k], J. Blümer[i,j], A. Broniatowski[e], V. Brudanin[h], P. Camus[f], A. Cazes[g], M. Chapellier[e], N. Coron[c], G.A. Cox[i], C. Cuesta[s], F.A. Danevich[l], M. De Jésus[g], L. Dumoulin[e], K. Eitel[j], A. Erb[o], A. Ertl[o], F. von Feilitzsch[o], D. Filosofov[h], N. Fourches[b], E. García[s], J. Gascon[g], G. Gerbier[b], C. Ginestra[s], J. Gironnet[g], A. Giuliani[e], M. Gros[b], A. Gütlein[o], D. Hauff[n], S. Henry[p], G. Heuermann[i], J. Jochum[r], S. Jokisch[j], A. Juillard[g], C. Kister[n], M. Kleifges[k], H. Kluck[i], E.V. Korolkova[q], V.Y. Kozlov[j], H. Kraus[p], V.A. Kudryavtsev[q], J.-C. Lanfranchi[o], P. Loaiza[m], J. Loebell[r], I. Machulin[u], S. Marnieros[e], M. Martínez[s], A. Menshikov[k], A. Münster[o], X.-F. Navick[b], C. Nones[b], Y. Ortigoza[s], P. Pari[a], F. Petricca[n], W. Potzel[o], P.P. Povinec[t], F. Pröbst[n], J. Puimedón[s], F. Reindl[n], M. Robinson[q], T. Rolón[s], S. Roth[o], K. Rottler[r], S. Rozov[h], C. Sailer[r], A. Salinas[s], V. Sanglard[g], M.L. Sarsa[s], K. Schäffner[n], B. Schmidt[i], S. Scholl[o], S. Schönert[o], W. Seidel[n], B. Siebenborn[i], M. v. Sivers[o], C. Strandhagen[r], R. Strauß[o], A. Tanzke[n], V.I. Tretyak[l], M. Turad[r], A. Ulrich[o], I. Usherov[r], P. Veber[d], M. Velazquez[d], J.A. Villar[s], O. Viraphong[d], R.J. Walker[b,i], S. Wawoczny[o], M. Weber[k], M. Willers[o], M. Wüstrich[o], E. Yakushev[h], X. Zhang[p], A. Zöller[o]

[a] CEA, Centre d'Études Nucléaires de Saclay, IRAMIS, 91191 Gif-sur-Yvette Cedex, France
[b] CEA, Centre d'Études Nucléaires de Saclay, IRFU, 91191 Gif-sur-Yvette Cedex, France
[c] CNRS, Institut d'Astrophysique Spatiale, Université Paris 11, Orsay 91405, France
[d] CNRS, Université de Bordeaux, ICMCB, 87 avenue du Dr. A. Schweitzer, Pessac cedex, 33608, France
[e] Centre de Spectroscopie Nucléaire et de Spectroscopie de Masse, UMR8609 IN2P3-CNRS, Univ. Paris Sud, Orsay Campus, 91405, France

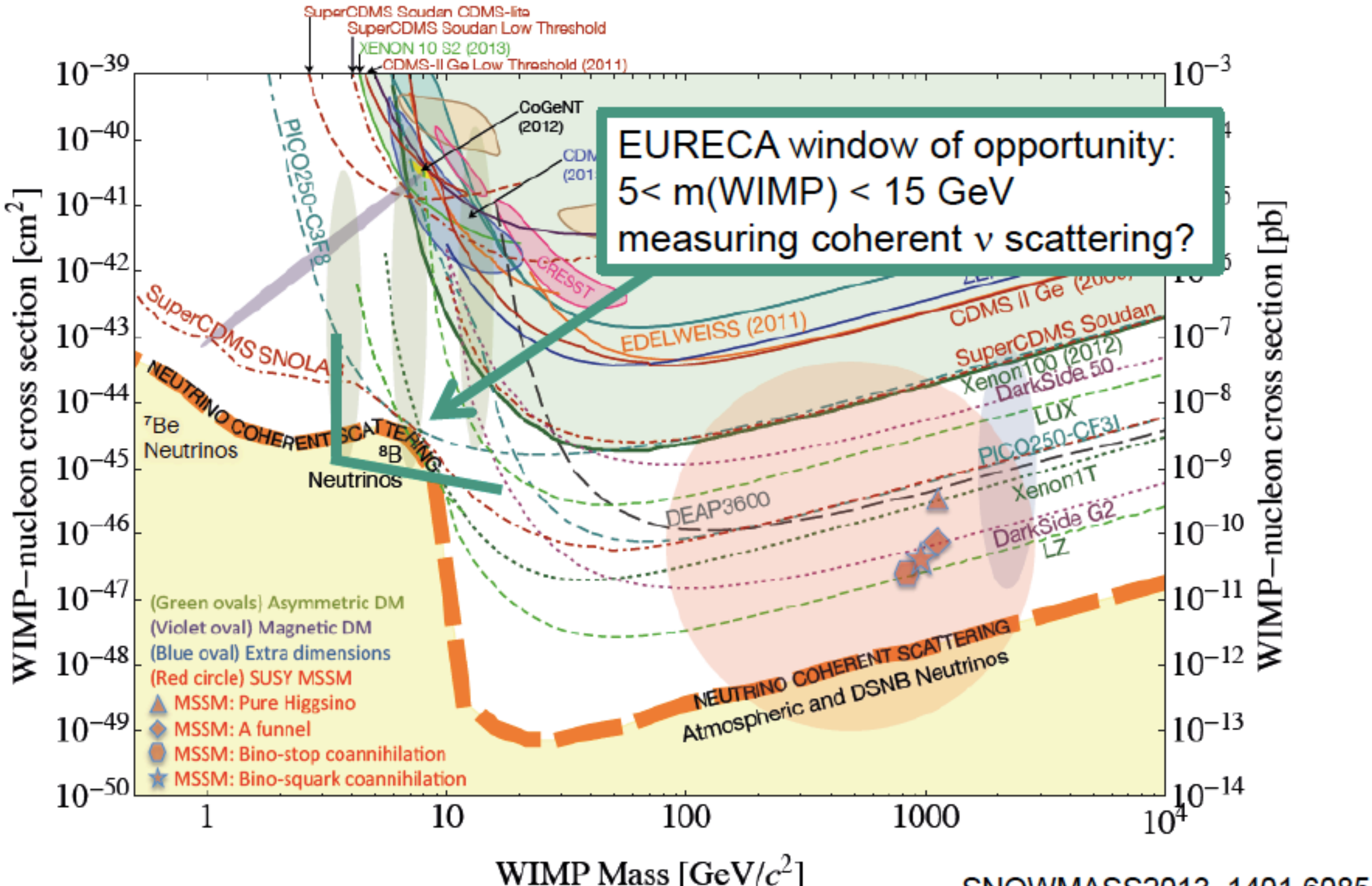
EURECA sensitivity as in CDR

1t detector mass Ge CaWO4
@ Modane extension



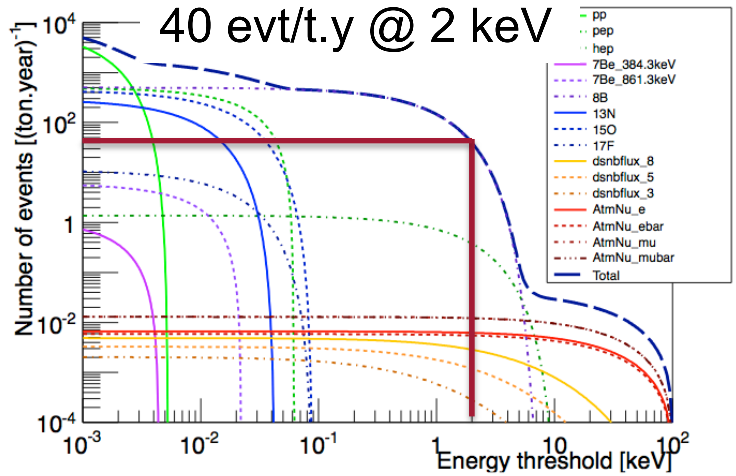
EURECA strategy change

March 2014



SNOWMASS2013, 1401.6085

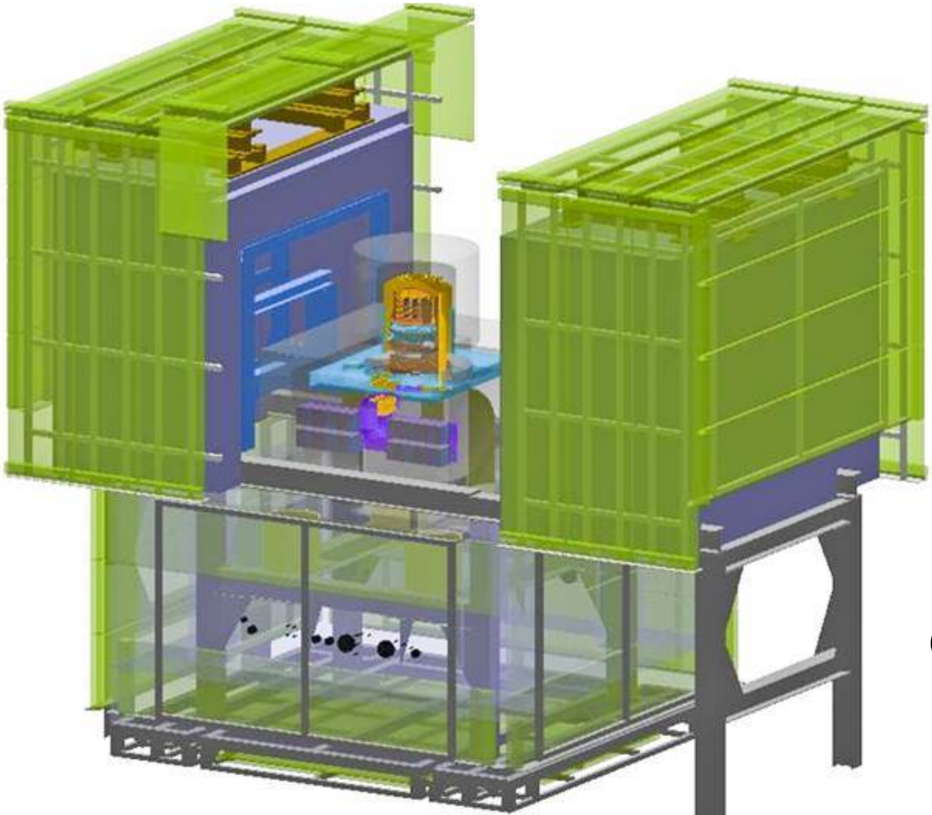
^{8}B neutrino "goal"



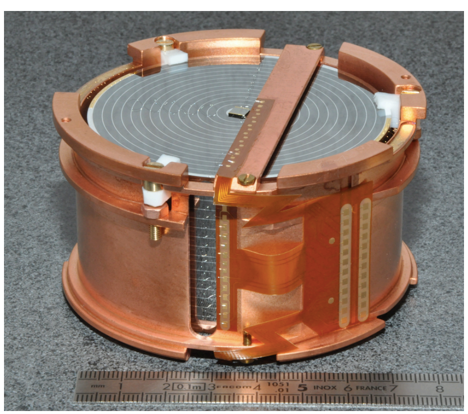
Jullien Billard :

- Neutrinos interact also through coherent scattering againt whole nuclei =>CNNS
- Example Ge
  - 1 evt/10 000 kg.d for Enr>2 keV
  - 10 evts = **100 kg fiducial for 3 years**
- What is needed ?
  - FID800 Ge : **FWHM ion = 200 eV, FWHM phonon = 500 eV**
  - Expected backg = 1 evt with ε=90 %
- Status now ?

EDELWEISS-III = French, German, Russian, UK @ Modane Lab



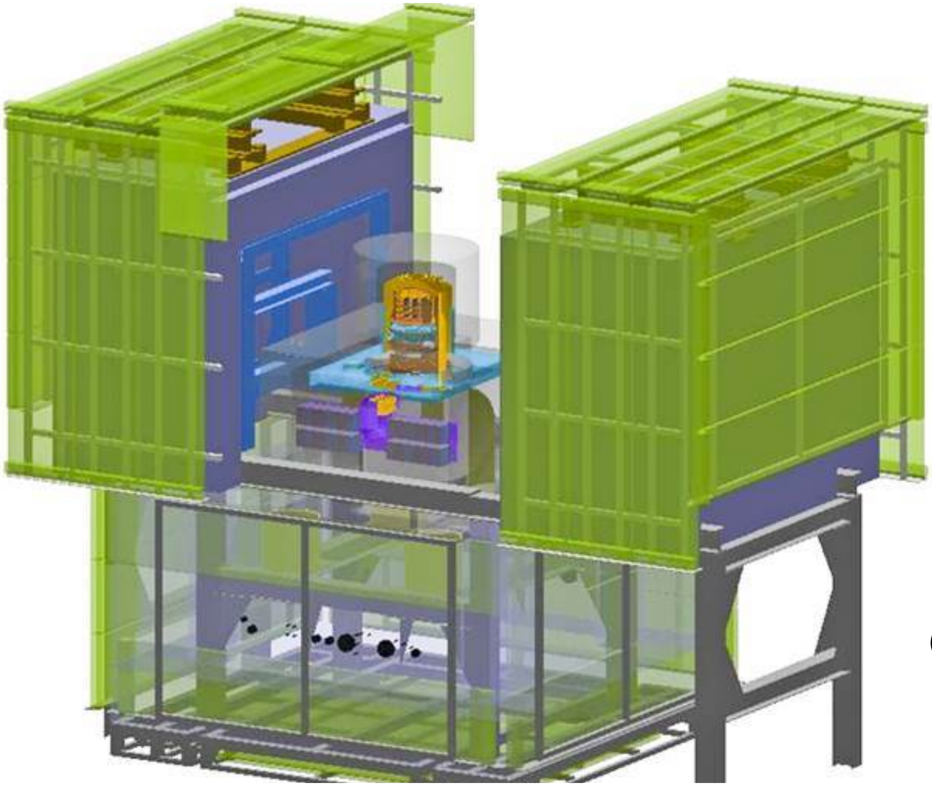
EDWIII Geant4 model



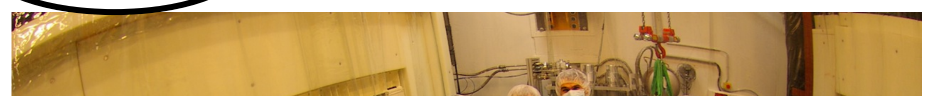
FID800

36 FID800 detectors operated at LSM

EDELWEISS-III = French, German, Russian, UK @ Modane Lab



36 FID800 detectors operated at LSM

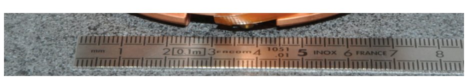


2014

- **500 eV FWHM ionization; 300-1000 eV FWHM on heats (8V polarisation)**
- **Now 600 kg.d for physics (after quality cuts+eff for wimp search) end 2014**

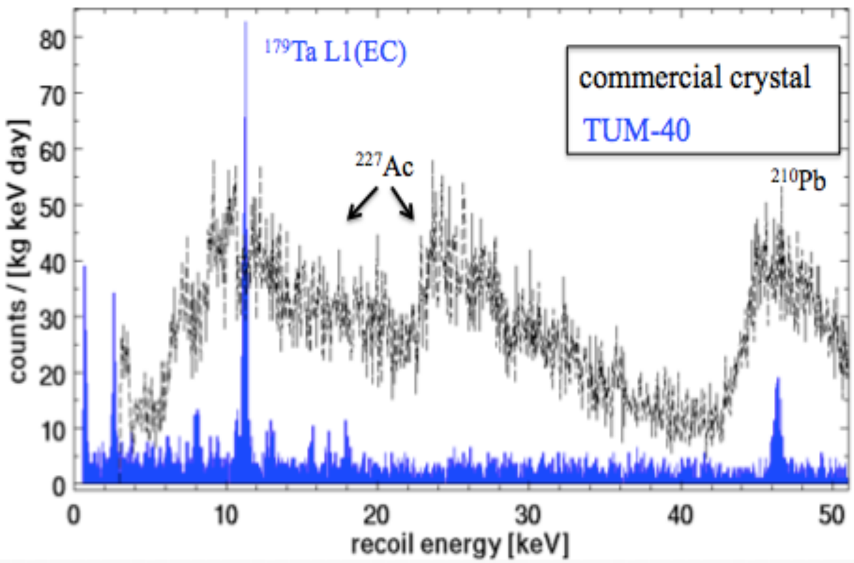
2015-2016

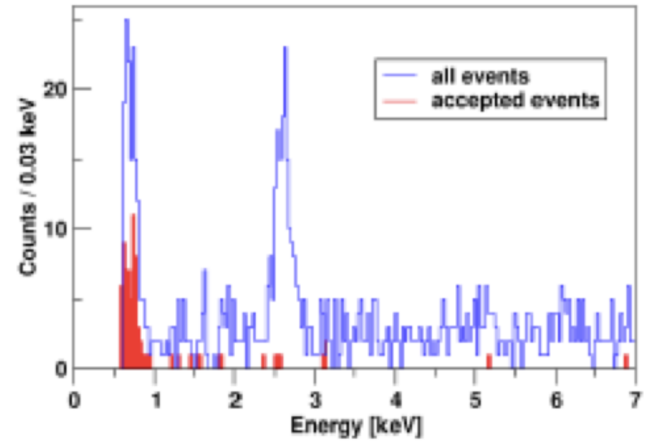
- Installation of Low Mass Detectors (improved FID800 with< **300eV FWHM** on both heat and ionisation (HEMT)



FID800

CRESST latest results



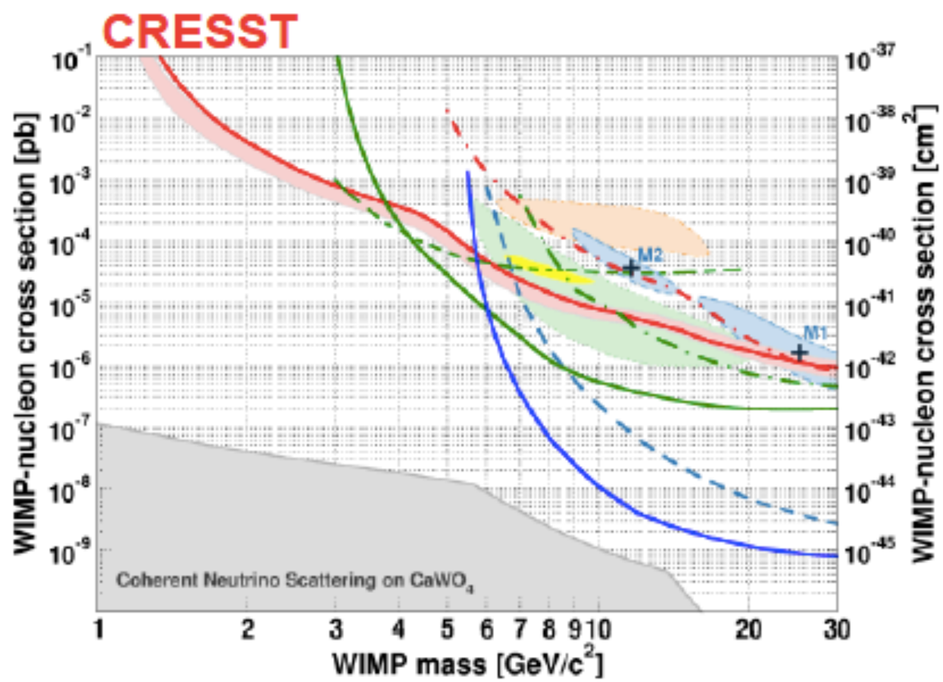


29.35 kg-d exposure

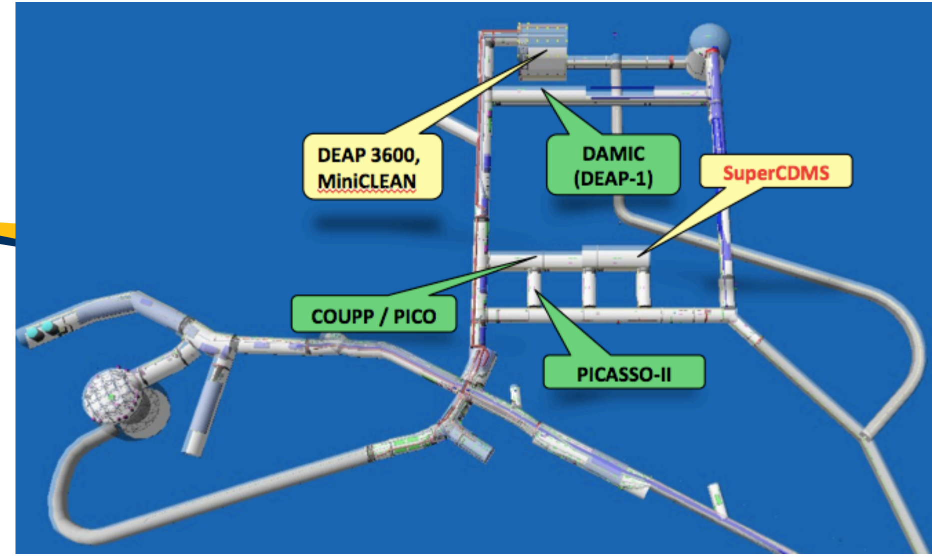
energy resolution: (107±3) eV

energy threshold: (603±2) eV

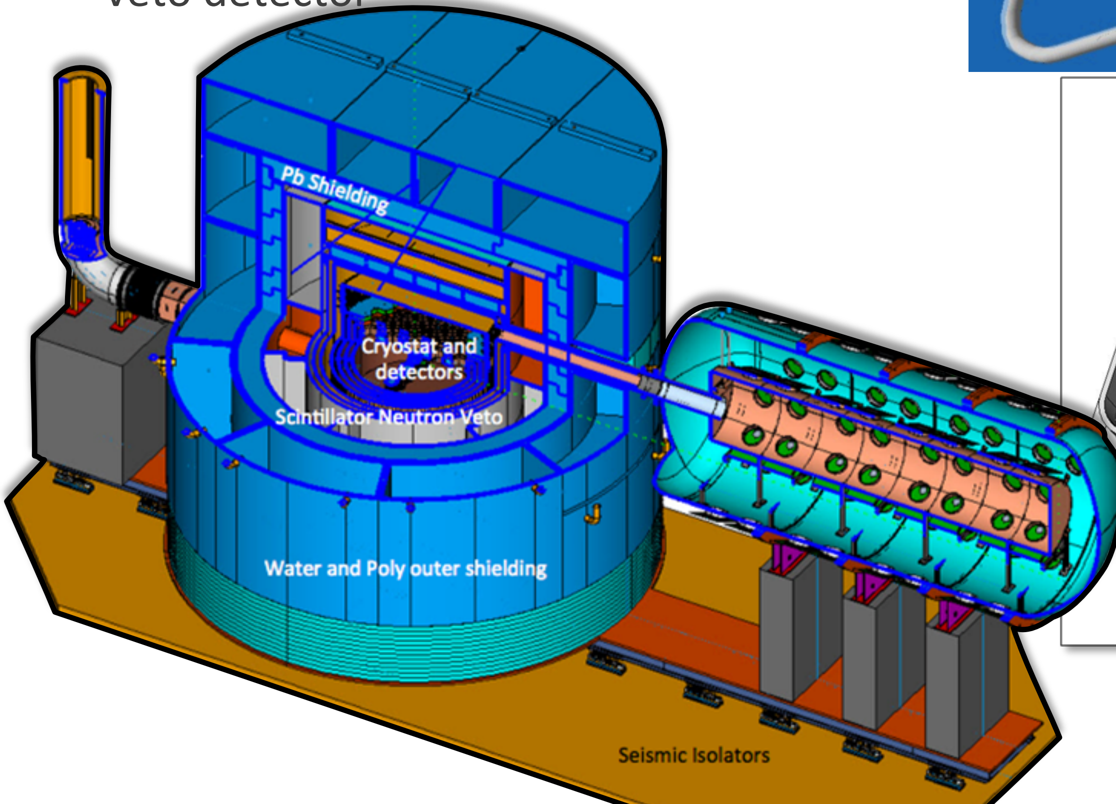
arXiv:1407.3146

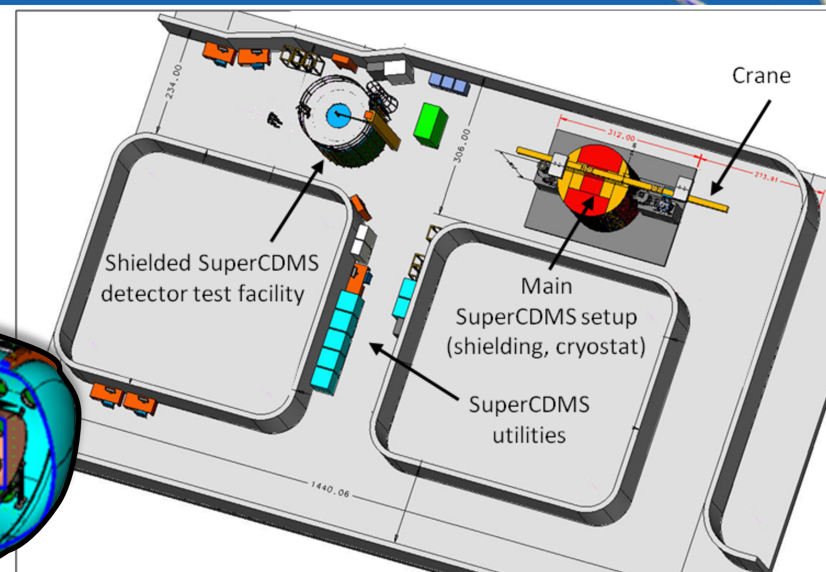


SuperCDMS at SNOLAB



- Setup holds up to ~400 kg detectors
- Planned shielding includes neutron veto detector

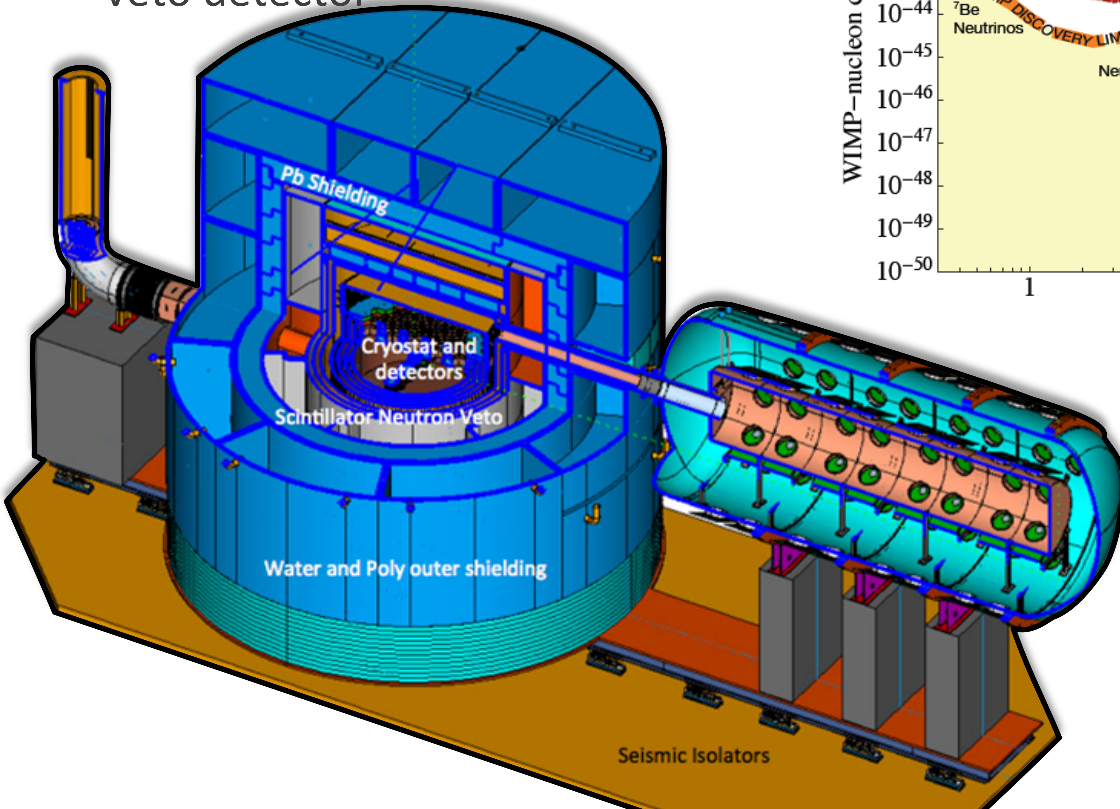


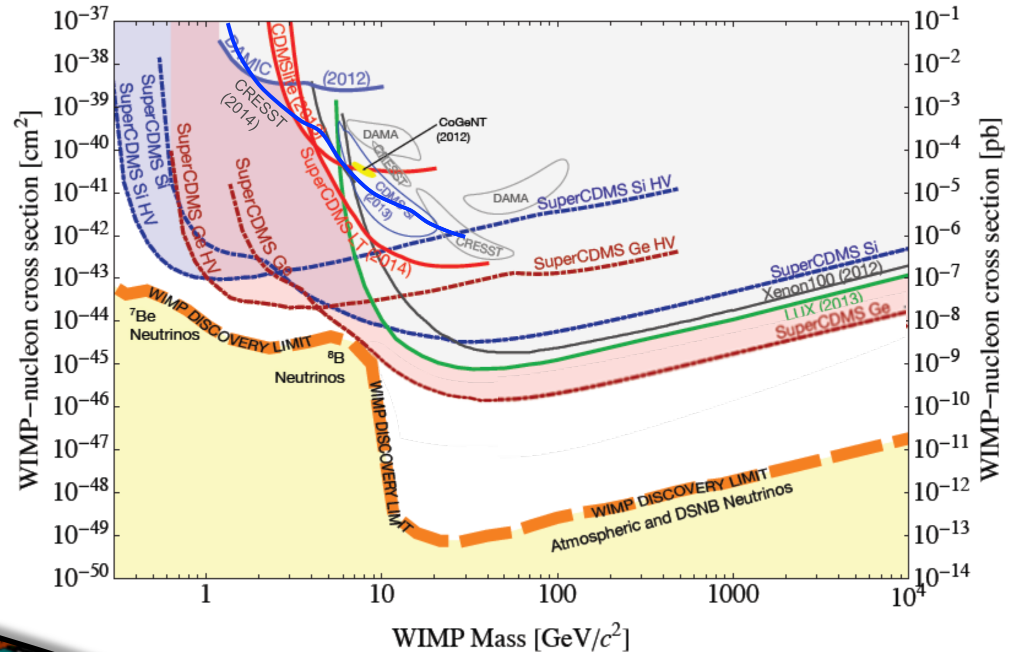


- **Funding: Selected by DOE/NSF as one of two "G2" WIMP search experiments**
- Total project cost: ~$25-30 M, including $3.4M from Canada (CFI)

SuperCDMS at SNOLAB

- Setup holds up to ~400 kg detectors
- Planned shielding includes neutron veto detector



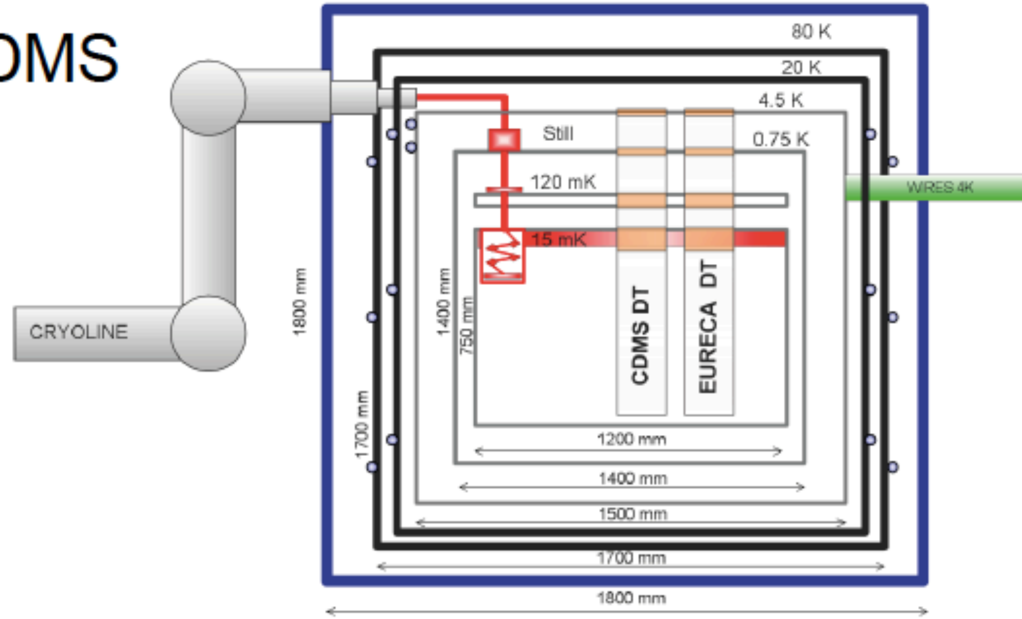


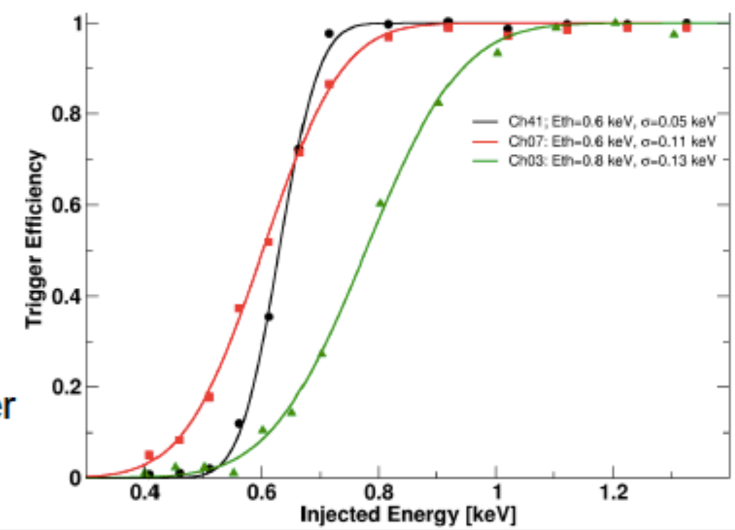
- Initial payload includes mix of standard and HV detectors (50 kg Ge, some Si)
- **Room for significant additional payload e.g. from EURECA (CRESST, EDELWEISS) or advanced HV dets.**

- **Funding: Selected by DOE/NSF as one of two "G2" WIMP search experiments**
- Total project cost: ~$25-30 M, including $3.4M from Canada (CFI)

Cooperation SuperCDMS/EURECA

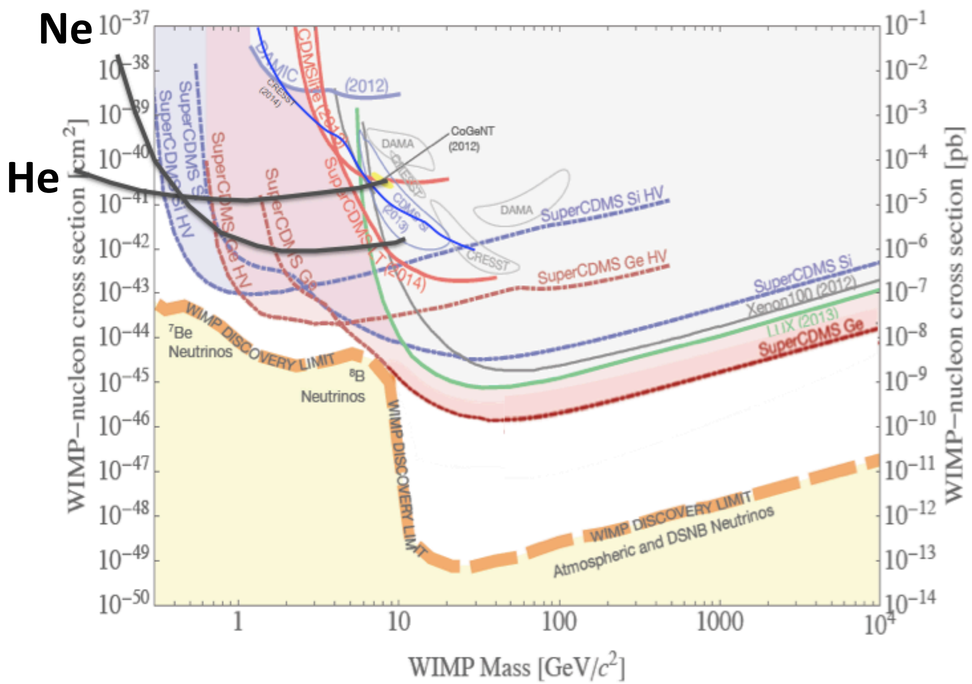
- cryogenic design for S-CDMS
  - with T≤15mK (cooling power 5µW)
    Institut Néel Grenoble, Saclay
- shielding concept
  - active water Cerenkov, borated liquid scintillator, full optical G4 model
    KIT, UMN, Kurchatov
- detector towers
  - design & build tower prototype compatible with S-CDMS concept
    Tübingen, TUM, KIT
- potential for low mass WIMPs
  - sub-keV(NR) efficiency for $CaWO_4$ crystals
  - "low mass" sensitivity with different target (Oxygen)
  - 2keV(NR) thresh for EDW-Ge, keeping discrim. power
  - complementing S-CDMS Ge detectors





GG contribution through CERC

- Reinforce SuperCDMS team @ Queen's
- Project of setting up tower test cryostat @ SNOLAB being investigated
- Also setting up experiment with light nuclei (H,He, Ne) as gaseous targets operated with spherical gas detector



Outlook

- Many theories & models pointing to low mass DM
  - Asymetric DM 5-6 GeV (K Zurek)
  - Dark Sector Mev-GeV range (P Schuster, N Toro @ PI)
  - Self interacting DM (S Tulin @ York)
  - …
- SuperCDMS @ SNOLAB will be unique worldwide infrastructure for cryogenic detectors
  - Ambiant local radioactivity decreased by 2 orders of magnitude
  - International coordination for
    - designing modular and optimised system for detector tower operations
    - optimising detectors to be used for GeV to 20 GeV DM exploration
- Significant role of Canada through UBC, Queen's and SNOLab teams