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GEODM
The Germanium Observatory for Dark Matter at DUSEL

Brief review of the field

- WIMPs: Does the physics at electroweak scale explain also dark matter?
- Direct Detection: Latest results of a fast expanding community
- The next 5 yrs: Complementarity between Direct Detection, Indirect and LHC
- The "competition": going to high target mass while staying background free

Dark Matter at DUSEL

- Physics scenarios: Discovery-> Observatory, no discovery, totally different physics
- The role of Germanium at low temperature: high signal/noise, perfect rejection
- GEODM: 1.5 ton Ge at 7400 ft at DUSEL. PI: Sunil Golwala

GEODM Engineering approach

- What makes sense for a project ≥ 10 years away: evolving baseline
- S4 NSF proposal, DOE companion proposal
- Involvement of LBNL

Why WIMPs ?

Bringing together cosmology and particle physics:

a remarkable concidence

Particles in thermal equilibrium

+ decoupling when nonrelativistic

Freeze out when annihilation rate ≈ expansion rate

Generic Class

$$\Rightarrow \Omega_x h^2 = \frac{3\cdot 10^{-27}\, cm^3/s}{\langle \sigma_A v\rangle} \Rightarrow \sigma_A \approx \frac{\alpha^2}{M^2_{EW}}$$

Cosmology points to W&Z scale

Inversely standard particle model requires new physics at this scale

(e.g. supersymmetry or additional dimensions)

=> significant amount of dark matter

Weakly Interacting Massive Particles

2 generic methods:

Direct Detection= elastic scattering

Indirect: Annihilation products

γ's e.g. 2 γ's at E=M is the cleanest

ν from sun &earth ≈ elastic scattering dependent on trapping time

$e^+, \bar{p}$

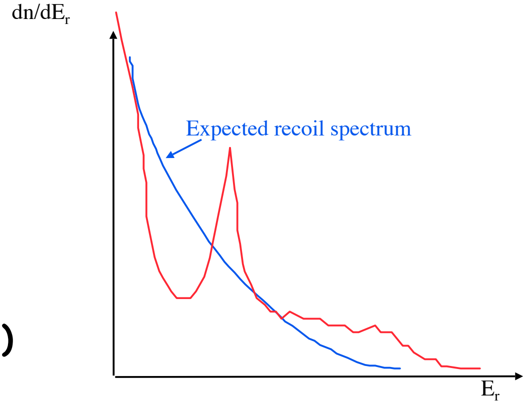
+ Large Hadron Collider

Direct Detection

Elastic scattering

Expected event rates are low
(<< radioactive background)
Small energy deposition (≈ few keV)
<< typical in particle physics

Signal = nuclear recoil (electrons too low in energy)
≠ Background = electron recoil **(if no neutrons)**



Signatures

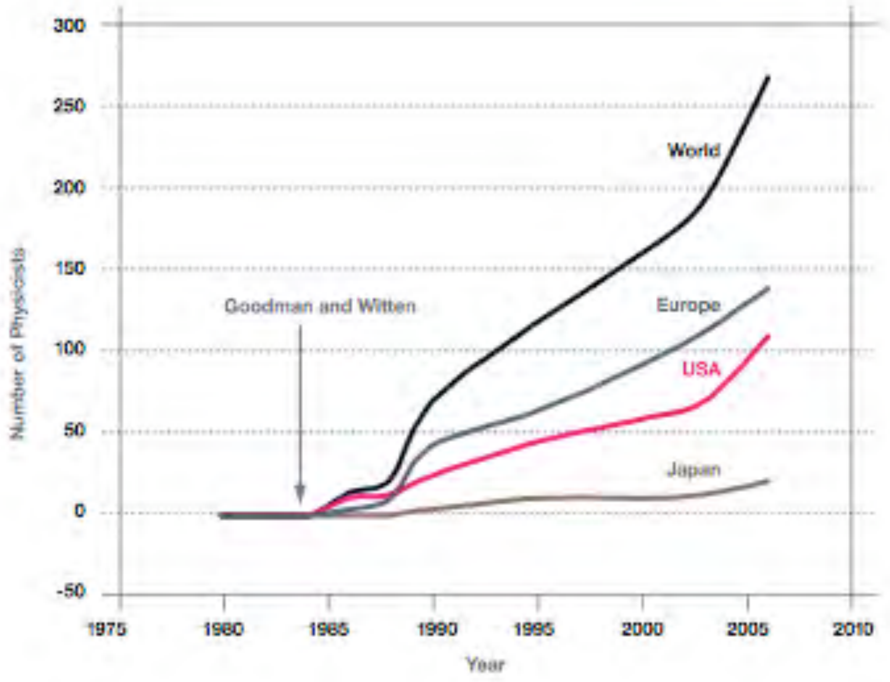
- Nuclear recoil
- Single scatter ≠ neutrons/gammas
- Uniform in detector

Linked to galaxy

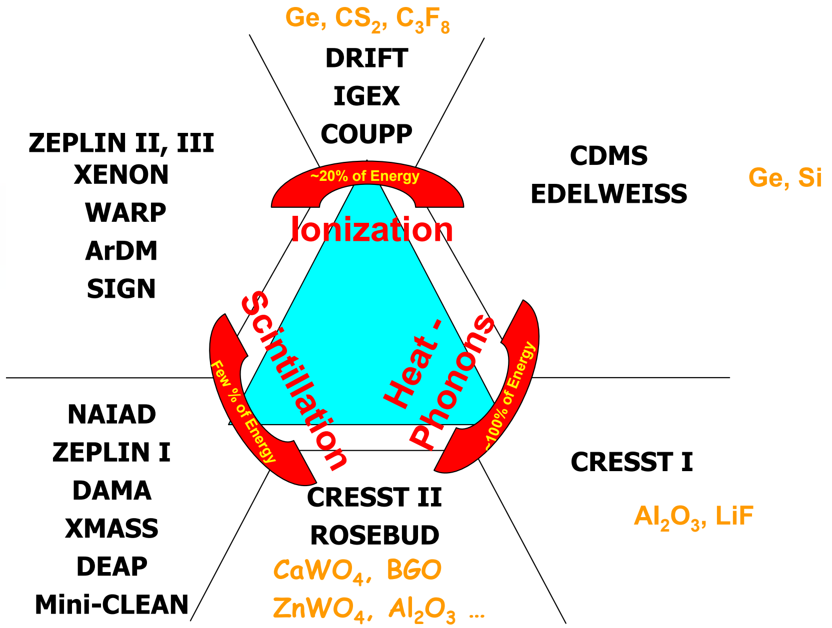
- Annual modulation (but need several thousand events)
- Directionality (diurnal rotation in laboratory but 100 Å in solids)

Experimental Approaches

A blooming field



Direct Detection Techniques



Ge, CS_2, C_3F_8
DRIFT
IGEX
COUPP

ZEPLIN II, III
XENON
WARP
ArDM
SIGN

CDMS
EDELWEISS
Ge, Si

NAIAD
ZEPLIN I
DAMA
XMASS
DEAP
Mini-CLEAN

CRESST II
ROSEBUD
$CaWO_4$, BGO
$ZnWO_4$, Al_2O_3 …

CRESST I
Al_2O_3, LiF

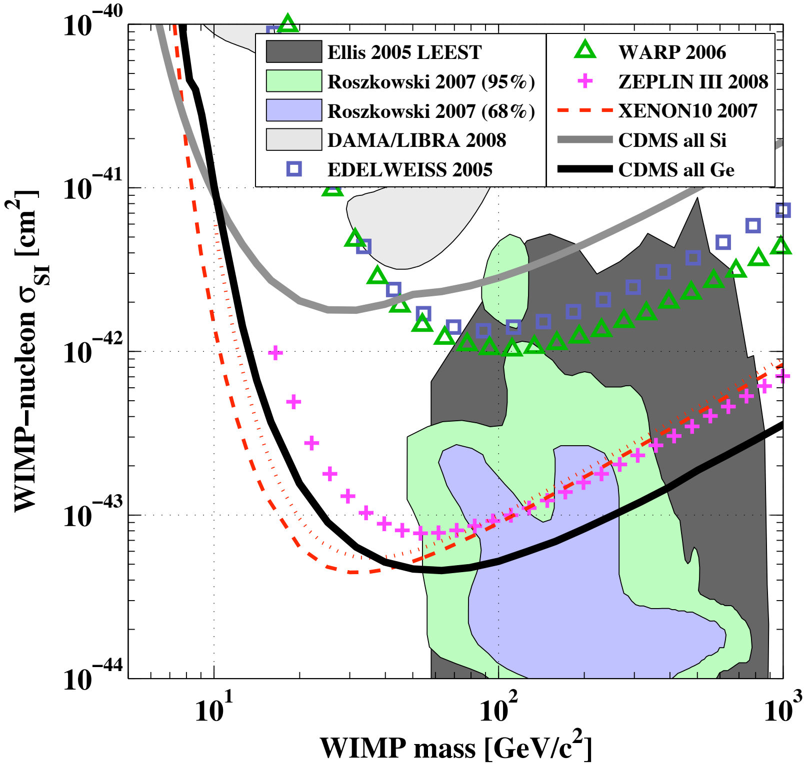
As large an amount of information and a signal to noise ratio as possible

At least two pieces of information in order to
- recognize nuclear recoil
- extract rare events from background (self consistency)
- + fiducial cuts (self shielding, bad regions)

Where are we? January 09

Scalar couplings: Spin independent cross sections

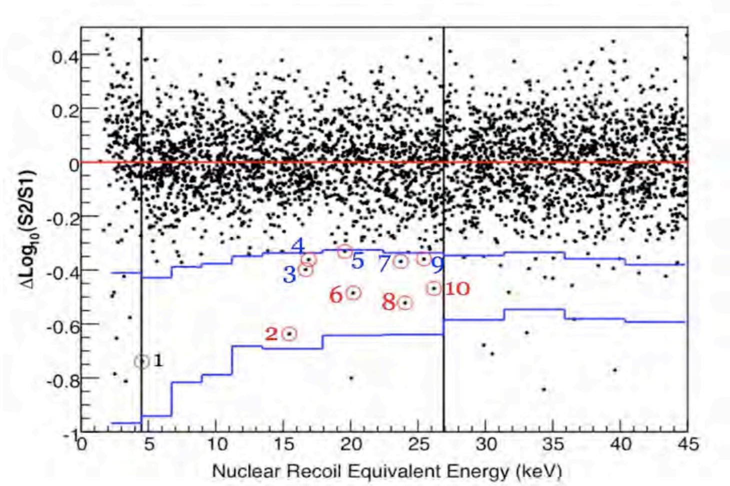
latest compilation by Jeff Filippini
Gray=DAMA 2 regions(Na, I) from Savage et al.

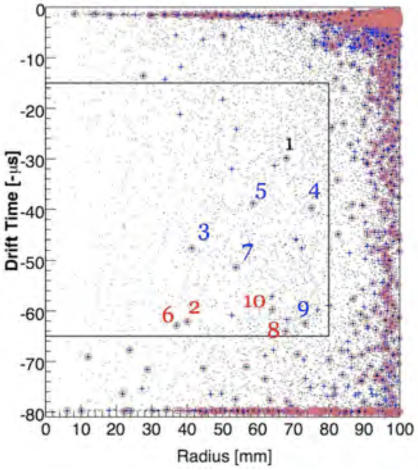


The 2 best experiments

Xenon 10 April 2007

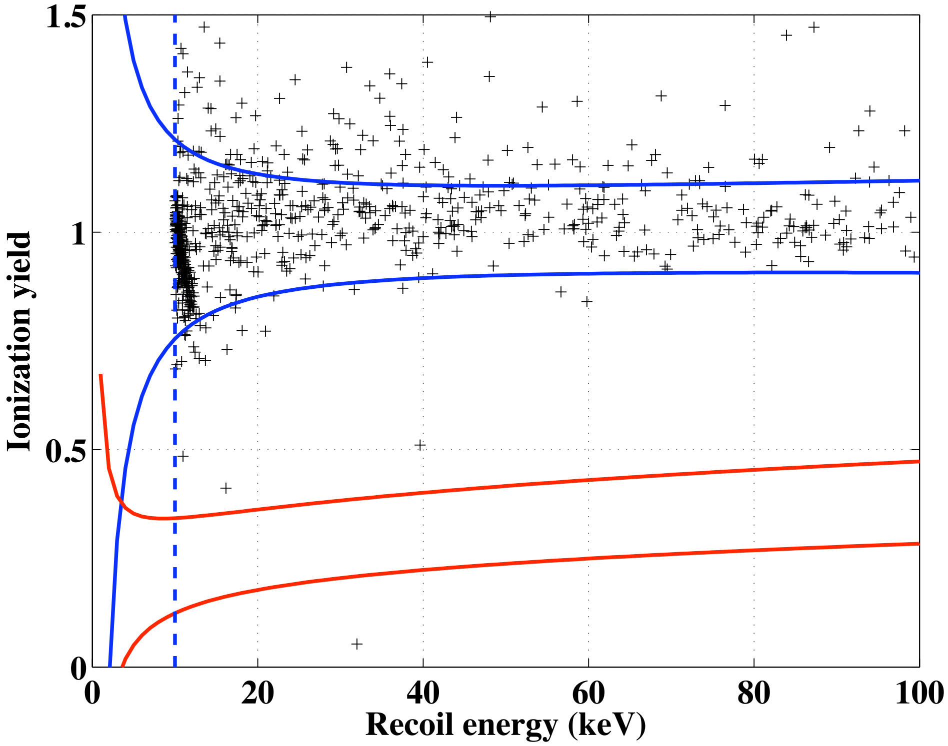
10 background events





CDMS II 0802.3530 PRL 102(2009)

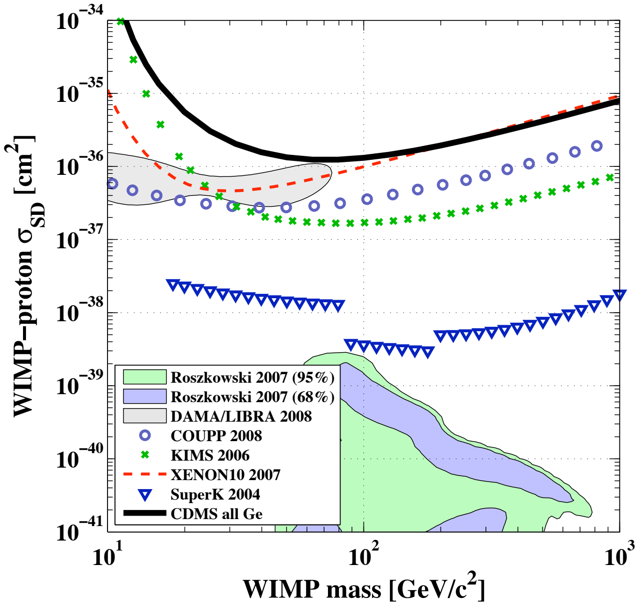
0 background event (Expected 0.6±0.5)

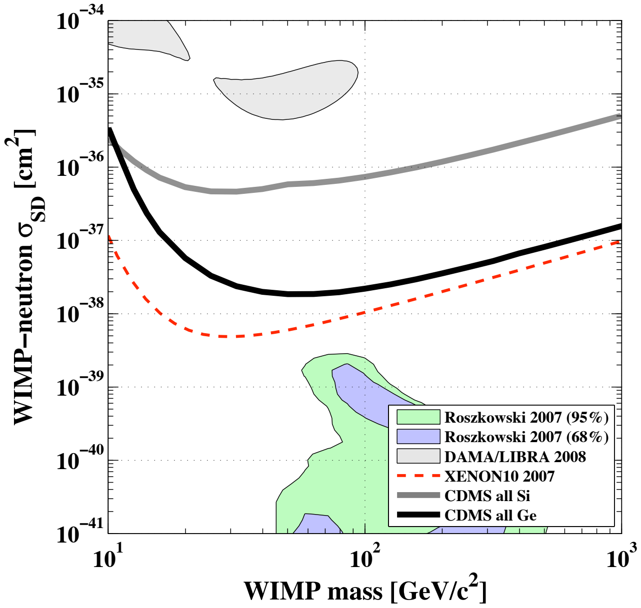


Discovery potential ≈5 times Xenon 10

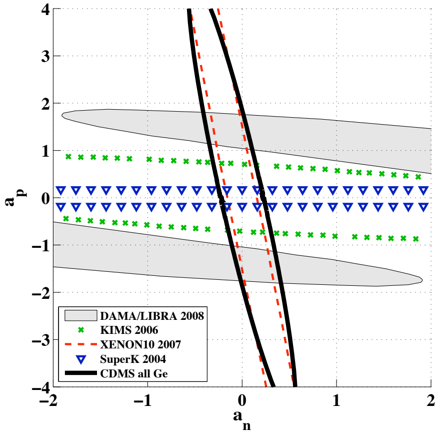
Where are we? January 2009

Spin dependent couplings





a_p vs a_n at mass of $60 GeV/c^2$

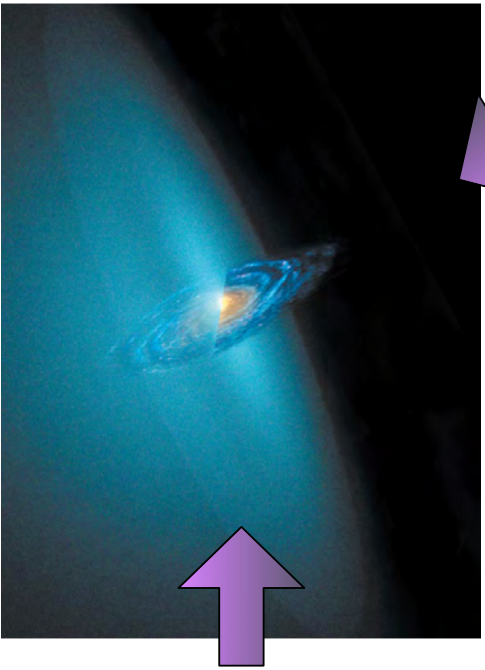


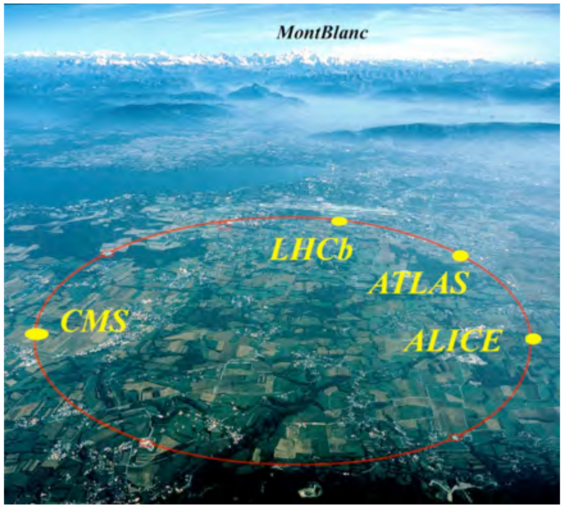
The next 5 years

WIMP scattering on Earth:
e.g. CDMS : currently
leading the field

Halo made of WIMPs

1/2 shown for clarity





WIMP production on Earth

WIMP annihilation in the cosmos

GLAST/Fermi
Launched 11 June 2008

We need all three approaches

Direct detection

May well provide a detection + ≈ cross section and mass
But what is the fundamental physics behind it?
What can we learn about the galaxy?

LHC

May well give rapidly evidence for new physics: missing energy
But is the stable? => need direct or indirect detection
Ambiguity in parameters: mass/cross section

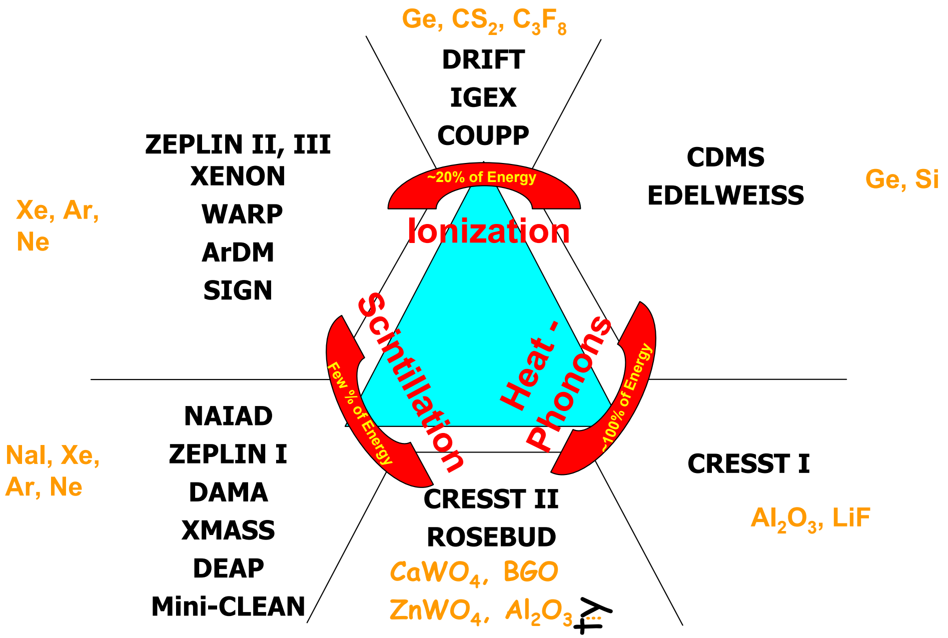
Indirect detection

May well provide smoking gun for both dark matter and hierarchical structure formation (subhalos)
But possible ambiguity in interpretation => need direct detection

Complementary sensitivity to different parameter space region

How to get to larger masses?

Direct Detection Techniques



Ge, CS_2, C_3F_8
DRIFT
IGEX
COUPP

ZEPLIN II, III
XENON
WARP
ArDM
SIGN

Xe, Ar, Ne

CDMS
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NAIAD
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DEAP
Mini-CLEAN

NaI, Xe, Ar, Ne

CRESST I

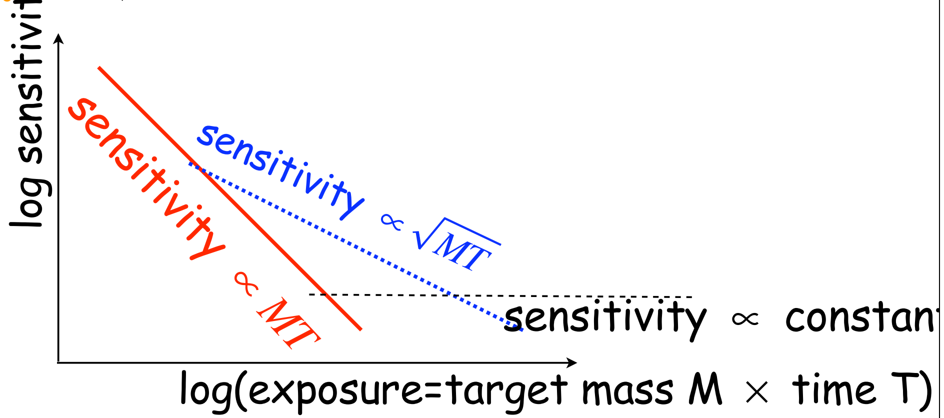
Al_2O_3, LiF

CRESST II
ROSEBUD

$CaWO_4$, BGO
$ZnWO_4$, Al_2O_3 ...

Three Challenges

- Understand/Calibrate detectors
- Be background free
  much more sensitive than
  background subtraction
  eventually limited by systematics
- Increase mass while staying background free



The Competition (a simplified view)

COUPP:

Bubble chamber 2 kg ->100 kg

Excellent upper bound machine?

sensitive to alpha contamination
not enough information for discovery

Liquid Xenon:

scintillation+ionization
self shielding ≈2.5 cm
10 kg->100 kg->20 tonne

Promising but not proven background

mediocre discrimination 99%
can be defeated by Rn diffusion
cosmogenics at DUSEL 4850ft
not cheap 1 ton of Xenon =$10M

Liquid Argon:

scintillation+ionization
pulse shape discrimination
2 kg->100 kg->50 tonne

Promising

need ^{39}Ar depletion (underground source)
far UV -> wave shifter, high threshold

Low temperature Ge:

phonons+ionization
Zero background so far
5kg->15kg->150kg->1.5 tonne

Promising extrapolation path

large 150 mm Ø, 50 mm thick crystal
large scale multiplexing (e.g. RF)
automation of TES process or KIDs separated function
simplification of testing

Many new ideas

Single phase-> simplicity
High or low pressure gas TPCs

Who will be the winners?

We do not know yet...

Likely to take some time of systematic work
Need strong R&D basically at full scale

Go beyond propaganda

"My detector is bigger than yours!"
Not the whole story: Detailed understanding of the phenomenology
Zero background!
One background can hide another one

In any case we need at least two different technologies

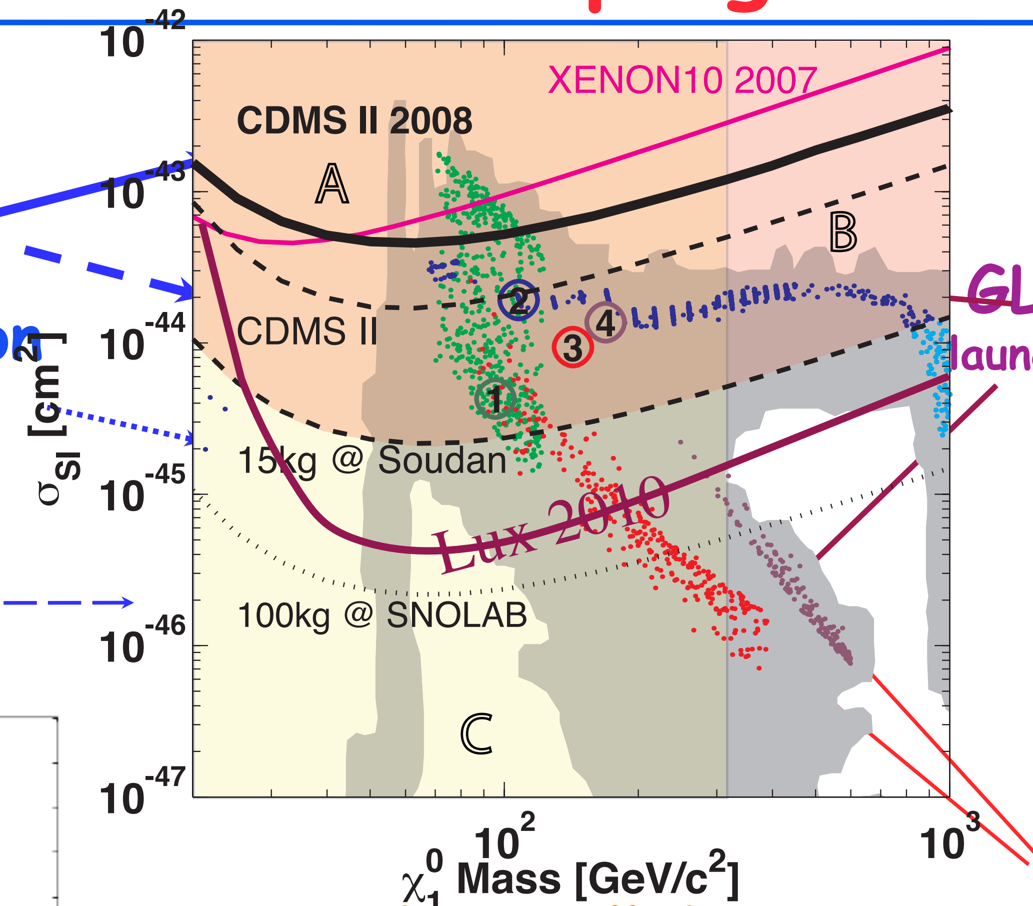
Cross checking each other
Protection against unexpected background
Physics! e.g.
Coherence additive quantum number: A^2 dependence (scalar coupling)
spin dependence
Threshold in target mass=> dark matter excited state

Pre DUSEL program

Current WIMP searches

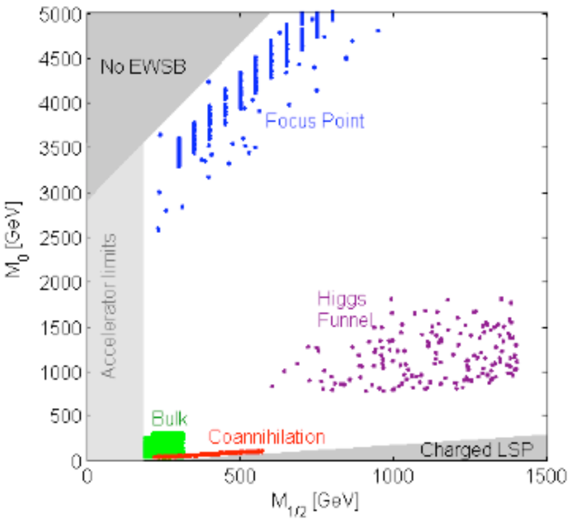
Next generation

1 generation beyond



GLAST/Fermi
launched 11 June 08

Finer and finer
tuning to get
right density!



Large Hadron Collider 09

Significant chance of discovery

10^{-45} cm^2 <2010 10^{-46} cm^2 <2015

Science complementary to LHC and Fermi-GLAST/ Ice Cube

What are the technologies of the future?

DUSEL Dark Matter Science

If we detect WIMPs, 3 obvious directions

1) Measurement of mass and detailed comparison with LHC and Fermi

We need large target masses to get statistics

2) Directionality => link to the galaxy

Low pressure TPC but probably need 100kg-1 ton: 1000-10000m^3 with mm^3 pixels

We need strong R&D now!

3) Detection of streams

Step in energy deposition: statistics+energy resolution

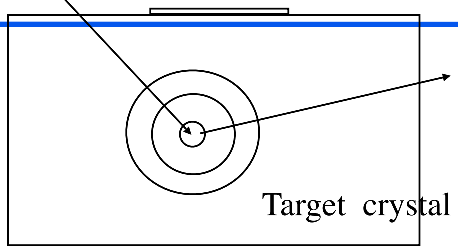
Directionality

If we have not detected WIMPs

Close loop holes and fine tuning regions

Importance of zero background!

The role of Germanium



Principle: Detect lower energy excitations

15 keV large by condensed matter physics standards

=> High signal to noise ratio

+ Several pieces of information
  - ionization
  - arrival time of athermal phonons
  - rise time

=> multidimensional discrimination

Only technique so far with zero background!

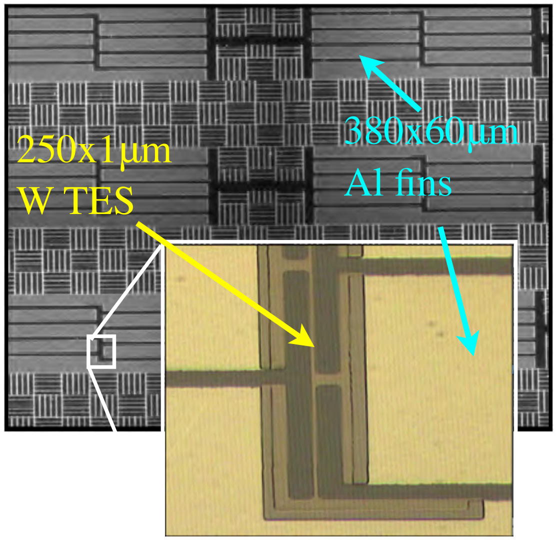
Xenon has to master contamination in liquid to be self shielding

Argon has to reduce/reject ^{39}Ar

Challenge: operation at low temperature

+ sophisticated technology

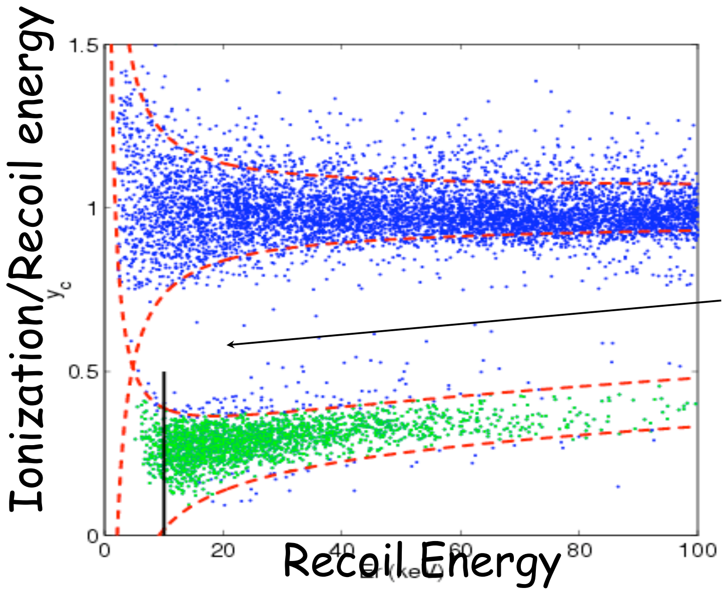
intensive in manpower for fabrication and testing



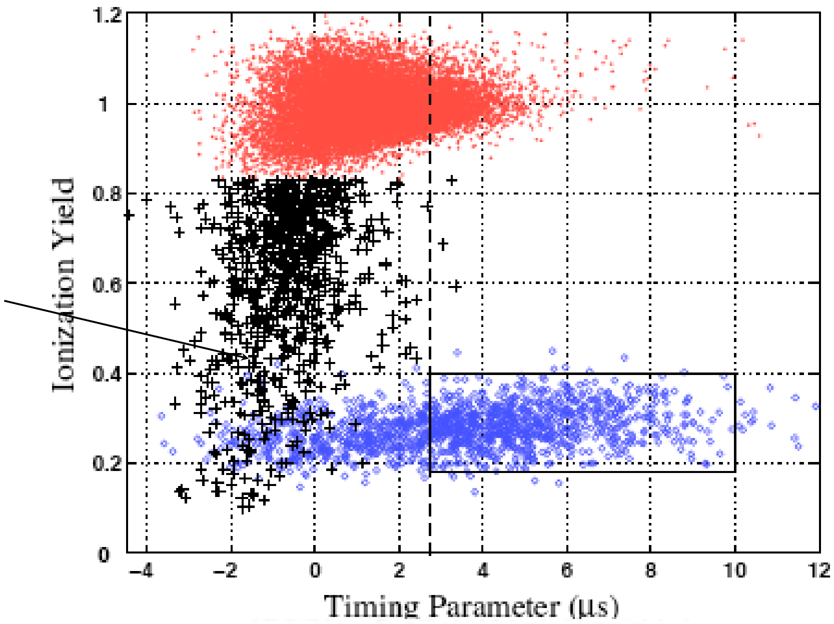
Multidimensional Discrimination

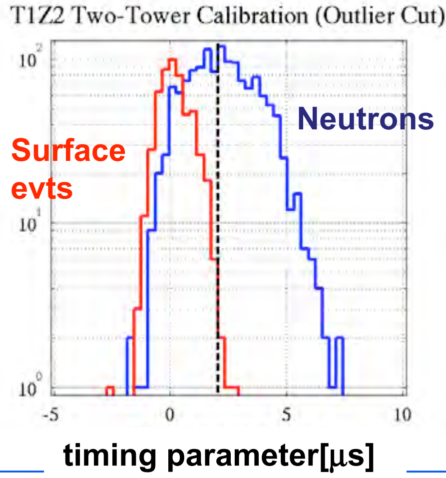
Ionization yield

Timing -> surface discrimination



Surface Electrons





Fix cuts blind (with calibration sources)

to get ≈0.5 events background

GEODM

Germanium Observatory for Dark Matter at DUSEL

PI: Sunil Golwala

Approach

- Large detector elements
  - 7.5cm diameter x 2.5cm thickness -> 15cm diameter x 5cm thickness
  - mass per detector 0.64 kg -> 5.1 kg
- At the same time maintain mass/sensor constant through multiplexing
  - Current baseline TES ≥32 per detector, dual sided
- Automation of production (in particular spinning/exposure of photoresist)
- Simplification of testing <= larger yield, if possible no implantation

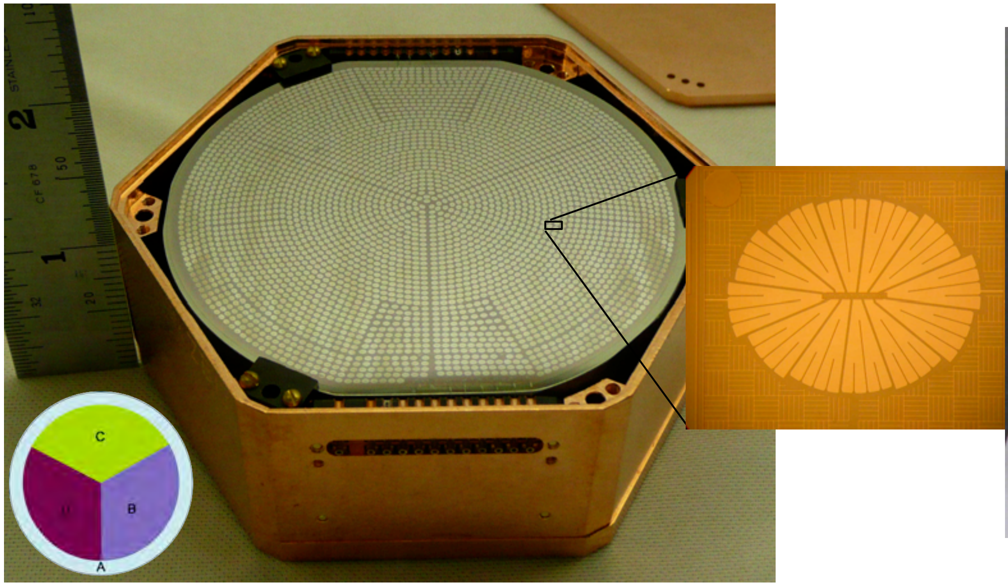
Scope

- 1.5 ton of Ge, $50M, 3 years construction
- Installation at 7800 ft (lower risk: no cosmogenic neutrons)
- Background reduction at source and improvement of rejection => 1/2000 CDMS II

2 10^{-47} cm^2 per nucleon in 4 years (2021)

Larger Detector Mass

SuperCDMS 15 kg detectors: 1cm-> 1" 250g ->635 g



Much larger detectors -> GEODM

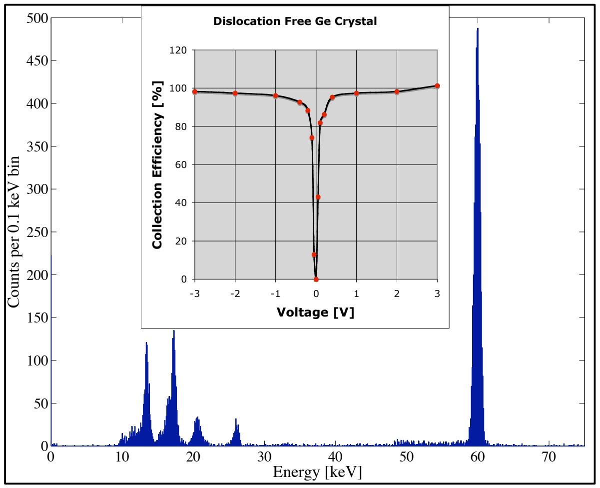
Liquid N2 Ge crystals limited to 3"

≈ 100 dislocation/cm^3

But we showed recently that dislocation free works at low temperature!

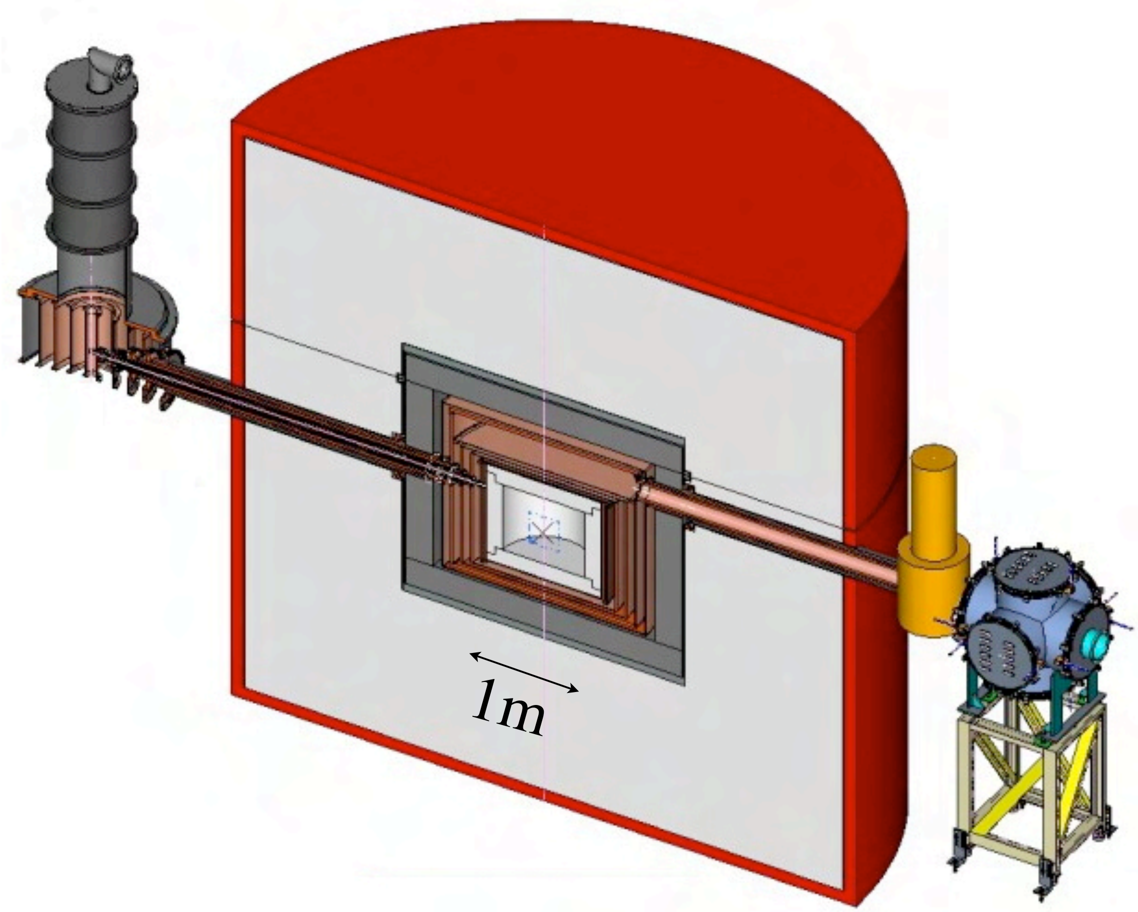
Umicore grows (doped) 8" crystal

6"x2" or 8"x1" ≈ 5kg + Multiplexing



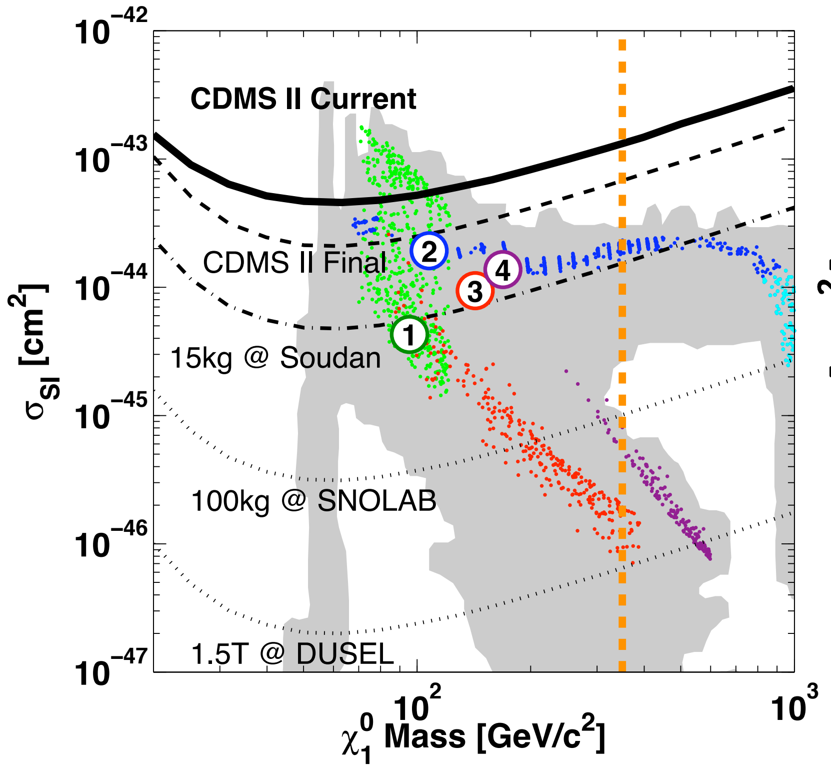
General Layout

Similar to SNOLAB set up that we are designing

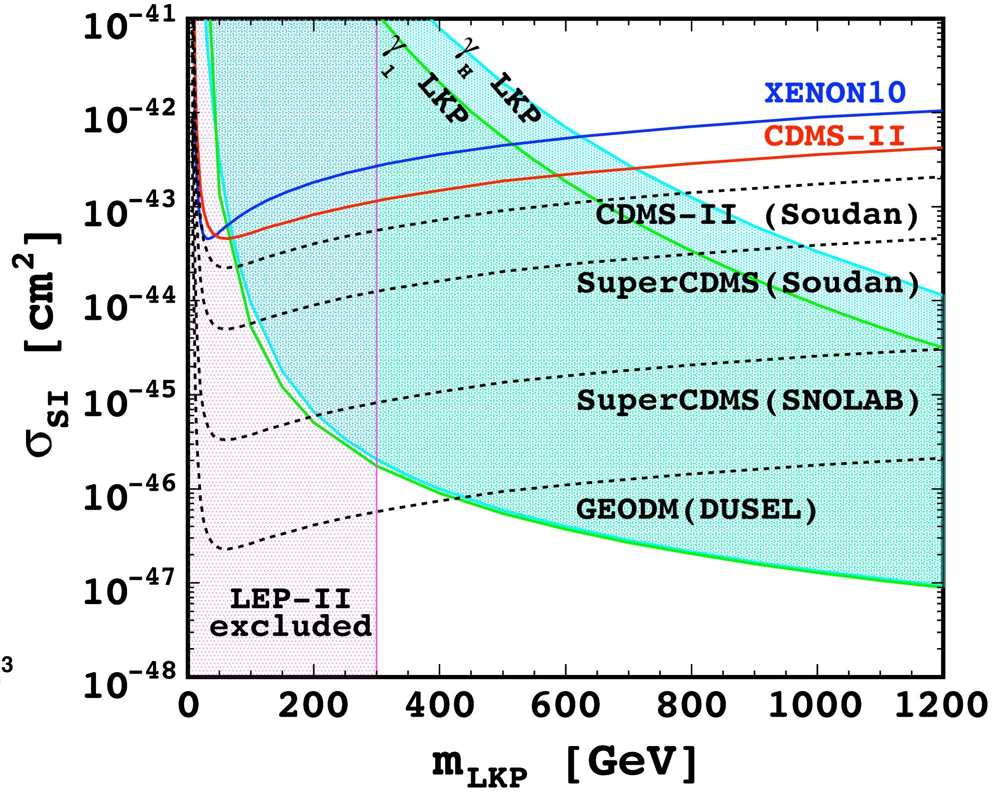


Physics Reach

Supersymmetry



Kaluza Klein

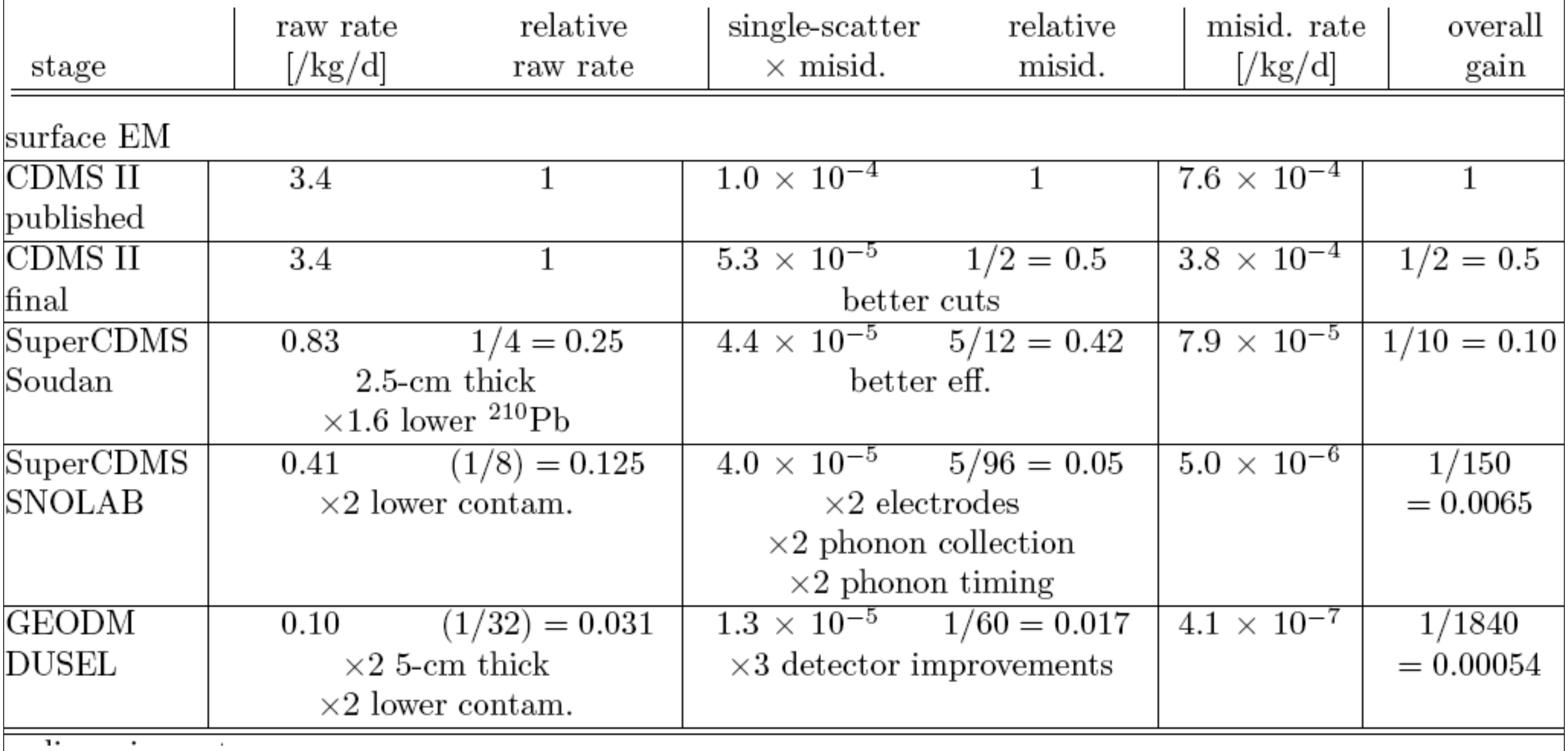


Bulk Electromagnetic Background

stage	raw rate [/kg/d]	relative raw rate	single-scatter × misid.	relative misid.	misid. rate [/kg/d]	overall gain
bulk EM						
CDMS II published	296	1	1.2×10^{-6}	1	7.2×10^{-4}	1
CDMS II final	296	1	5.9×10^{-7} better cuts	$1/2 = 0.5$	3.6×10^{-4}	$1/2 = 0.5$
SuperCDMS Soudan	296	1	1.9×10^{-7} 2.5-cm thick, better eff.	$1/6 = 0.17$	1.2×10^{-4}	$1/6 = 0.17$
SuperCDMS SNOLAB	180 internal shield	$(3/5) = 0.6$	1.2×10^{-8} 5-cm thick, ×2 electrodes ×2 phonon collection ×2 phonon timing	$1/96 = 0.01$	4.5×10^{-6}	$1/160$ $= 0.00625$
GEODM DUSEL	45 better stock/shield	$(3/20) = 0.15$	4×10^{-9} ×3 detector improvements	$1/300 = 0.003$	3.6×10^{-7}	$1/2000$ $= 0.0005$

Progression that we believe is reasonable

Surface Electromagnetic Background



stage	raw rate [/kg/d]	relative raw rate	single-scatter × misid.	relative misid.	misid. rate [/kg/d]	overall gain
surface EM						
CDMS II published	3.4	1	1.0×10^{-4}	1	7.6×10^{-4}	1
CDMS II final	3.4	1	5.3×10^{-5} better cuts	$1/2 = 0.5$	3.8×10^{-4}	$1/2 = 0.5$
SuperCDMS Soudan	0.83 2.5-cm thick ×1.6 lower ^{210}Pb	$1/4 = 0.25$	4.4×10^{-5} better eff.	$5/12 = 0.42$	7.9×10^{-5}	$1/10 = 0.10$
SuperCDMS SNOLAB	0.41 ×2 lower contam.	$(1/8) = 0.125$	4.0×10^{-5} ×2 electrodes ×2 phonon collection ×2 phonon timing	$5/96 = 0.05$	5.0×10^{-6}	$1/150$ $= 0.0065$
GEODM DUSEL	0.10 ×2 5-cm thick ×2 lower contam.	$(1/32) = 0.031$	1.3×10^{-5} ×3 detector improvements	$1/60 = 0.017$	4.1×10^{-7}	$1/1840$ $= 0.00054$

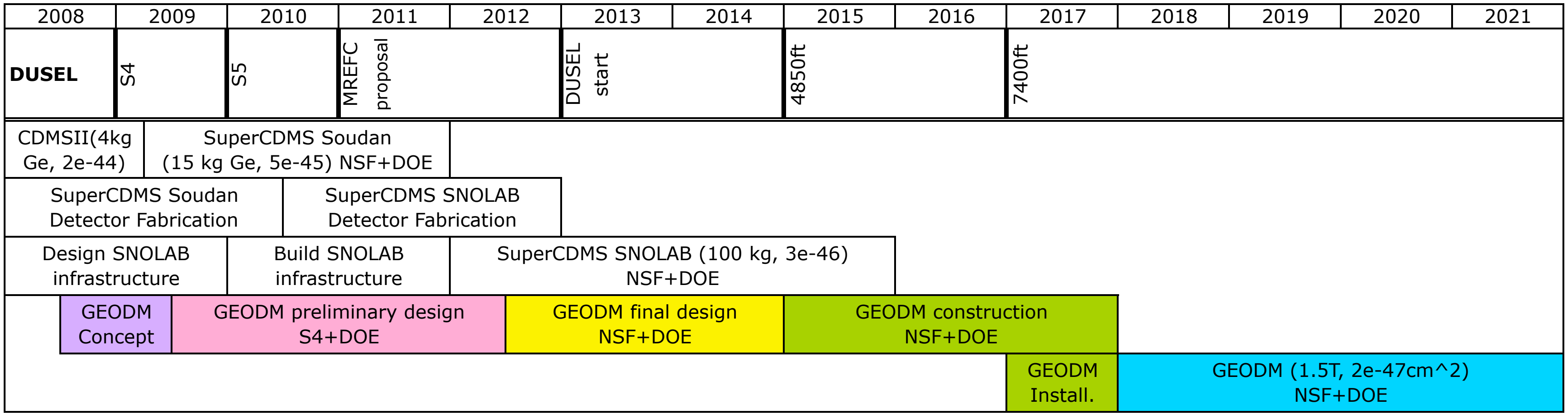
Progression that we believe is reasonable

Radiogenic Neutrons

stage	raw rate [/kg/d]	relative raw rate	single-scatter × misid.	relative misid.	misid. rate [/kg/d]	overall gain
radiogenic neutrons						
CDMS II published	1.2×10^{-4}	1	1	1	1.2×10^{-4}	1
CDMS II final	1.2×10^{-4}	1	1	1	1.2×10^{-4}	1
SuperCDMS Soudan	1.2×10^{-4}	1	1	1	1.2×10^{-4}	1
SuperCDMS SNOLAB	6.0×10^{-6} better stock/shield	$1/20 = 0.05$	1	1	6.0×10^{-6}	$1/20 = 0.05$
GEODM DUSEL	4.0×10^{-7} better stock/shield	$(1/300) = 0.003$	1	1	4.0×10^{-7}	$1/300 = 0.003$

Low risk

Schedule and costs



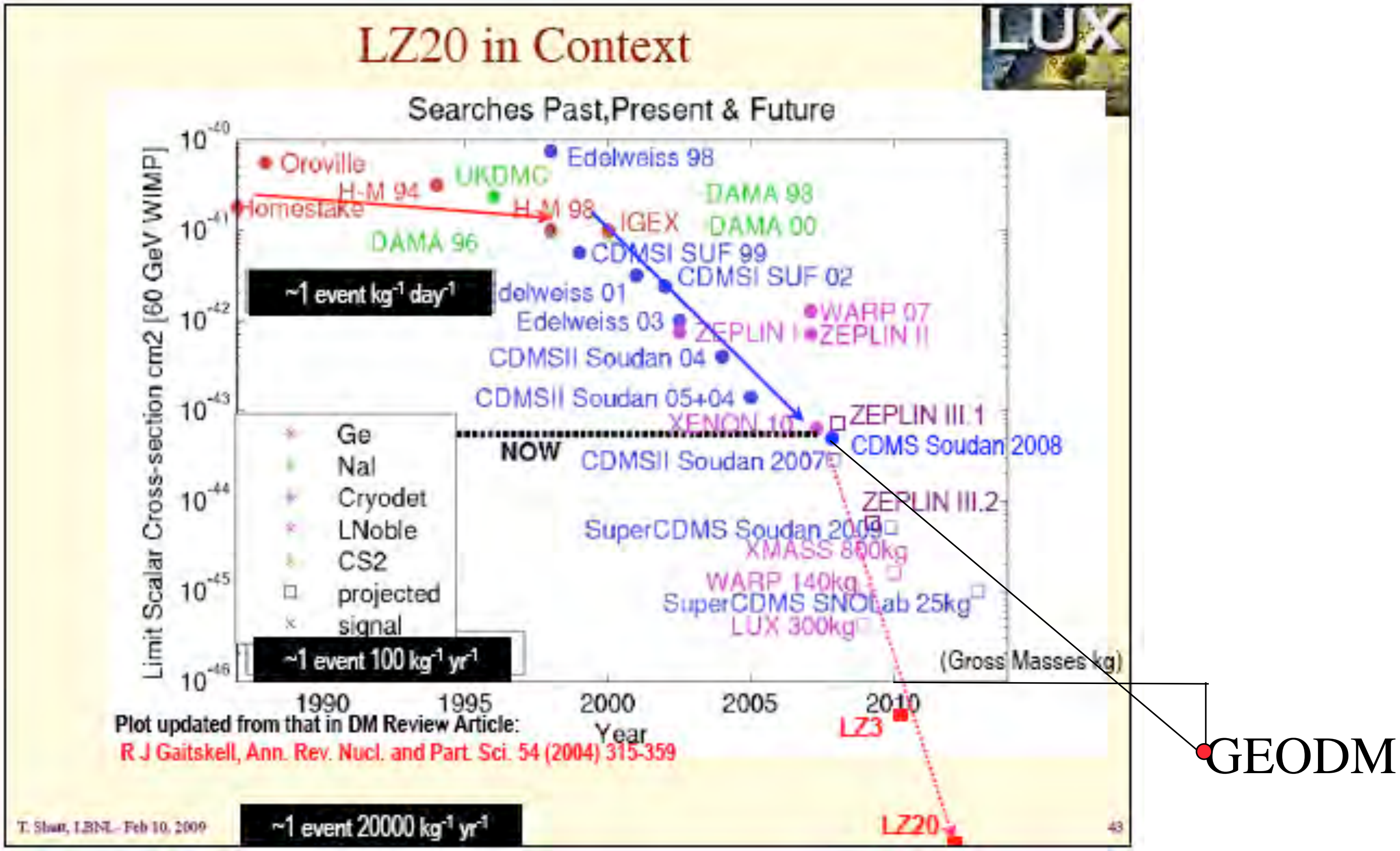
GEODM= natural succession to Soudan/SNOLAB

SNOLAB brings resilience to program e.g. against DUSEL slippage

Subsystem	SuperCDMS Soudan	GEODM
Detector Production (incl. cold electronics and hardware)	\$ 5.6	\$36M
Warm Electronics	\$ 0.125M	\$ 2M
Cryostat/Shield	\$ 3.1M	\$10M
DAQ	\$ 0.1M	\$ 1M
Lab Interface/Experimental Enclosure	\$ 0.5M	\$ 1M
Total	\$ 9.4M	\$50M

Table 1: Cost summary for SuperCDMS Soudan and GEODM

GEODM in perspective



LZ20 in Context

Plot updated from that in DM Review Article:
R J Gaitskell, Ann. Rev. Nucl. and Part. Sci. 54 (2004) 315-359

T. Shutt, LBNL- Feb 10, 2009

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More or less on current historical curve of progress

May be "blown out of the water" by noble liquids but no evidence so far!

Engineering Approach

General strategy

GEODM will not take place for at least 9 years
- Not bound by current technical solutions : Explore phase space
- But profit from technical legacy

Present as much as possible a baseline design ≠arborescence of choices
- Coherent set of choices

Evolution of baseline design as new approaches become available from long term R&D
- Facilitated by "generic solutions" when they are available e.g.
  - Towers that could accommodate high impedance wiring
  - RF multiplexing that can accommodate both TES and Kinetic Inductance

Sensor Baseline

W transition edge

Very significant recent improvements

- Full wafer exposure with EB aligner => much higher yield
- Higher purity target: lower Tc => maybe no need to implant
- Possibility of automation of spinning / exposure/baking

Multiplexing

- Time multiplexing 10MHz may be limited to 16 channels
- RF frequency multiplexing 400MHz: 128 channels

Double side read out with AC/RF biasing

- 35% efficiency-> 70%
- solves low impedance biasing of TES on side of high impedance ionization read out
  - 635g -> 1.2 kg equivalent

R&D in progress

Kinetic inductance instead of TES

Advantages: Not dissipative, no noise from quasiparticles if T<<Tc

No sharp transition=> reproducibility

In some schemes: separation of functions (probe wafers)

Readily multiplexable with RF multiplexing

But have to control noise from substrate + microphonics

Arriving to CD2

S4 is not sufficient

$2.065

Focus on highest risk items

Companion DOE proposal

LBNL lead?

$1.75M

Core FNAL and SLAC

≈$1.6M

Task	Base	SuperCDMS SNOLAB	NSF S4	companion DOE	DUSEL R&D	Other
background simulations	×	×				
low-bgnd materials sourcing	×	×				×
detector design	×	×			×	
large detector fab/automation			×			
detector test automation			×			
cold hardware/ electronics	×			×		×
warm electronics	×	×		×		
cryostat/shield	×	×		×		×
DAQ/analysis	×			×		
lab interface/safety			×			

LBNL Involvement

Scientific opportunity

+ complementarity to LHC and Dark Energy programs

More generally: Does the lab wants a leadership role in Dark Matter?

A $50M experiment

needs much more engineering and project control than a smaller experiments

- We need the lab to arrive at a credible CD2 (expertise + resources)
- Mass production and testing more aligned with national lab expertise/ capability

Natural partnership with Fermilab (Cryogenics, warm electronics) and SLAC (detector fabrication, automatic testing)

Aligned with service role of the laboratory

Division of responsibility still open

In addition to interface with DUSEL and safety (natural for LBNL)

- Ge large crystals and contact (Haller, Luke)
- Cold electronics (FET, SQUIDs, RF elements) and hardware (mechanical+ electronic engineering)
- RF multiplexing (fast ADC/DAC, FGPA)

Overlap with other goals (LBNL as a leader in instrumentation e.g. Majorana, CUORE, Homeland security, CMB, high resolution gamma)

Need young people with 20 year horizon

≥1 Divisional Fellow

Conclusions

Importance of the pre-DUSEL program

Significant chance of discovery

10^{-45} cm^2 <2010 10^{-46} cm^2 <2015

Science complementary to LHC and Fermi-GLAST/ Ice Cube

What are the technologies of the future?

We need to start to develop now DUSEL program

GEODM : only technology that is background free so far

<= High signal to noise, multidimensional discrimination

The technology can be simplified significantly

- Large crystals
- Large scale multiplexing
- Faster fabrication and testing

Involvement of LBNL

Makes scientific sense for the lab to take lead in dark matter

We need the lab (+FNAL and SLAC)

Overlap between needed R&D and other lab priorities (instrumentation)

Need to engage a younger generation (e.g. DUSEL Divisional Fellows)