WIMP Dark Matter Searches into the Next Decade with SuperCDMS and the Germanium Observatory for Dark Matter (GEODM)

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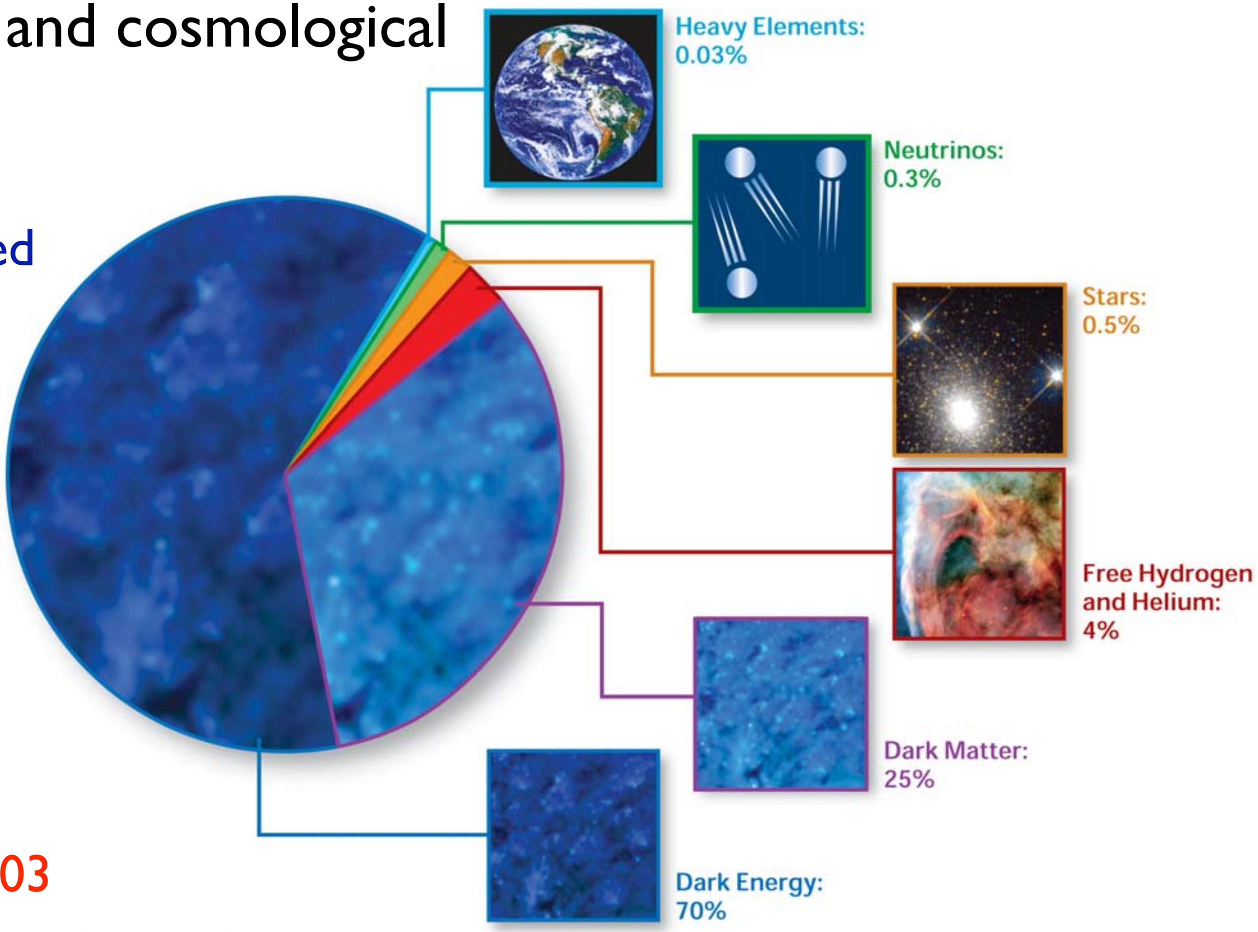
MIT LNS Lunch Seminar

Sep 8, 2009

Outline

- Motivation: the need for dark matter, WIMPs as a candidate
- CDMS II summary
- From CDMS II to SuperCDMS and GEODM
  - Backgrounds
  - Background rejection
  - Detector fab/test costs and timescales
  - Status/Timeline

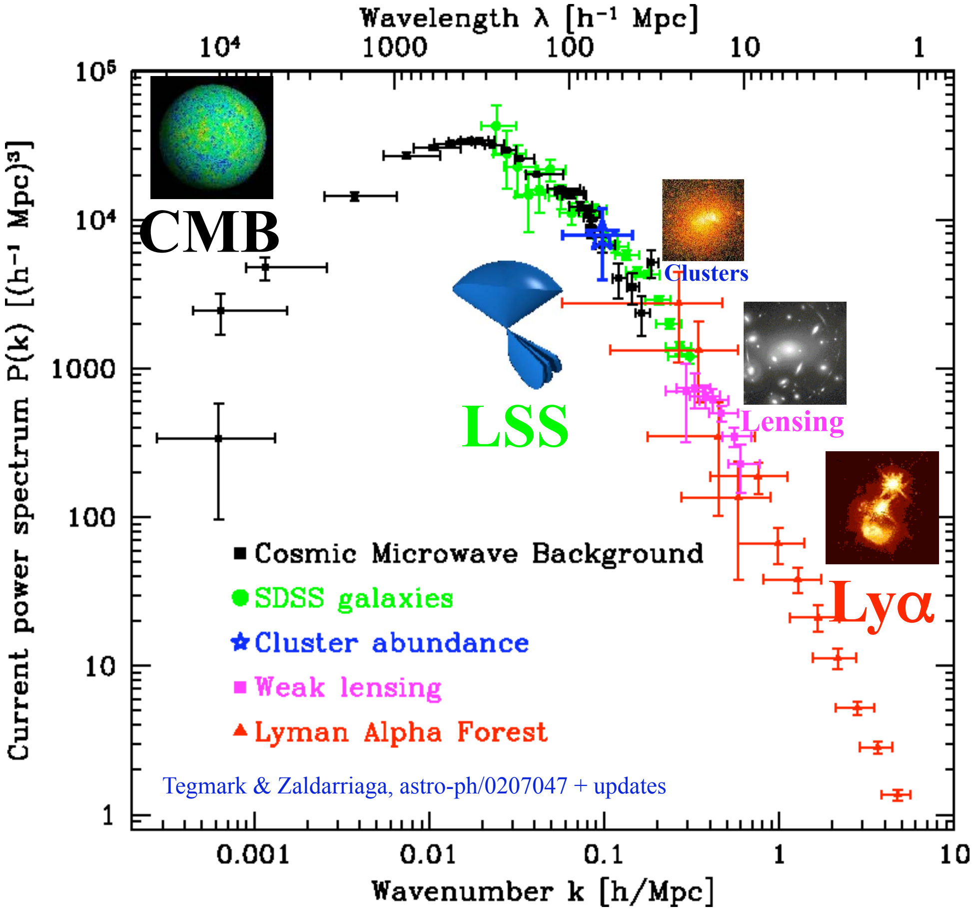
Why Dark Matter?



- A host of astronomical and cosmological observations indicate:
  - Total energy density = critical density ρ_{crit} needed for spatially flat universe (within errors)
  - The bulk is in the form of *dark energy*, a fluid that has negative pressure (causes the universe's expansion to accelerate) and does not clump gravitationally, $\Omega_{DE} = \rho_{DE}/\rho_{crit} = 0.73 \pm 0.03$
  - Most of the matter is in the form of *dark matter*, matter that interacts gravitationally but not electromagnetically, $\Omega_{DM} = \rho_{DM}/\rho_{crit} = 0.20 \pm 0.03$
  - The remaining matter is in the form of baryons, $\Omega_B = \rho_B/\rho_{crit} = 0.042 \pm 0.004$ (though most of this has not yet been directly observed!)

Required Dark Matter Characteristics

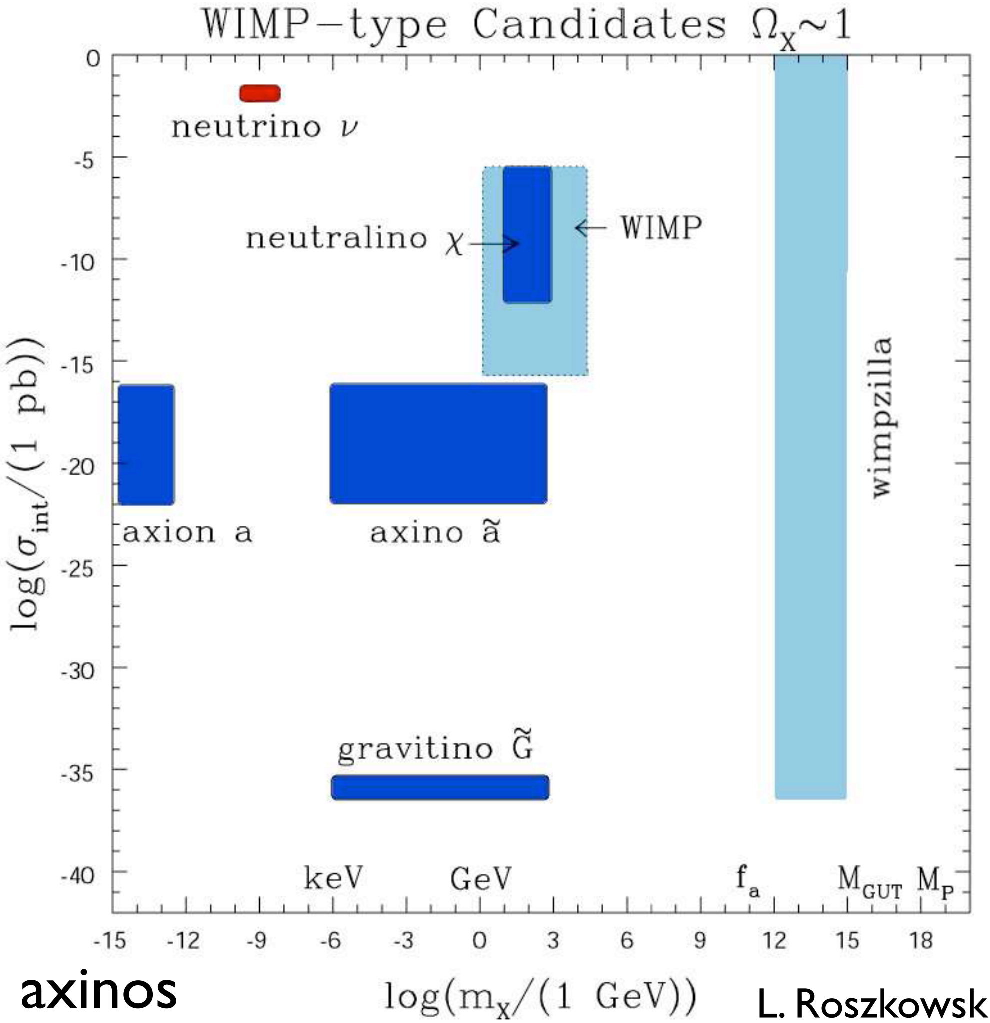
- Dark matter must be:
  - Cold/warm (not hot):
    - nonrelativistic at matter-radiation equality ($z \sim 3500$) to seed LSS. $M <$ keV (e.g., ν) too hot.
  - Nonbaryonic
    - Light element abundances + Big Bang Nucleosynthesis measure baryon density: too low.
    - Baryonic matter could not collapse until recombination ($z \sim 1100$): too late to seed LSS



Tegmark & Zaldarriaga, astro-ph/0207047 + updates

- Locally, we know
  - density ~ 0.1-0.7 GeV/cm^3: ~1 proton/3 cm^3, ~1 WIMP/coffee cup
  - velocity: simplest assumption is Maxwell-Boltzmann distribution with $\sigma_v \approx 270$ km/s (recently increased based on VLBA maser measurements!)

The Particle Dark Matter Zoo



L. Roszkowski

- Neutrinos
  - massive neutrinos can be *cold* or *warm*; low-mass neutrinos are *hot*
- Axions
  - Form as Bose condensate in early universe: cold in spite of low mass
- Weakly Interacting Massive Particles (WIMPs)
  - new massive (~100 GeV) particle with EW scale interactions
  - SUSY neutralino
  - Lightest Kaluza-Klein particle in universal extra dimensions
- SUSY gravitinos (SuperWIMPs) and axinos
- Less compelling candidates:
  - Inelastic dark matter, excited dark matter, WIMPzillas, SIMPzillas, primordial black holes, Q-balls, strange quark nuggets, mirror particles, CHArged Massive Particles, self interacting dark matter, D-matter, cryptons, brane world dark matter...

WIMPs

- A WIMP δ is like a massive neutrino: produced when T >> m_δ via pair annihilation/creation. Reaction maintains thermal equilibrium.
- If interaction rates high enough, comoving density drops as $\exp(-m_\delta / T)$ as T drops below m_δ : annihilation continues, production becomes suppressed.
- But, weakly interacting → will "freeze out" before total annihilation if

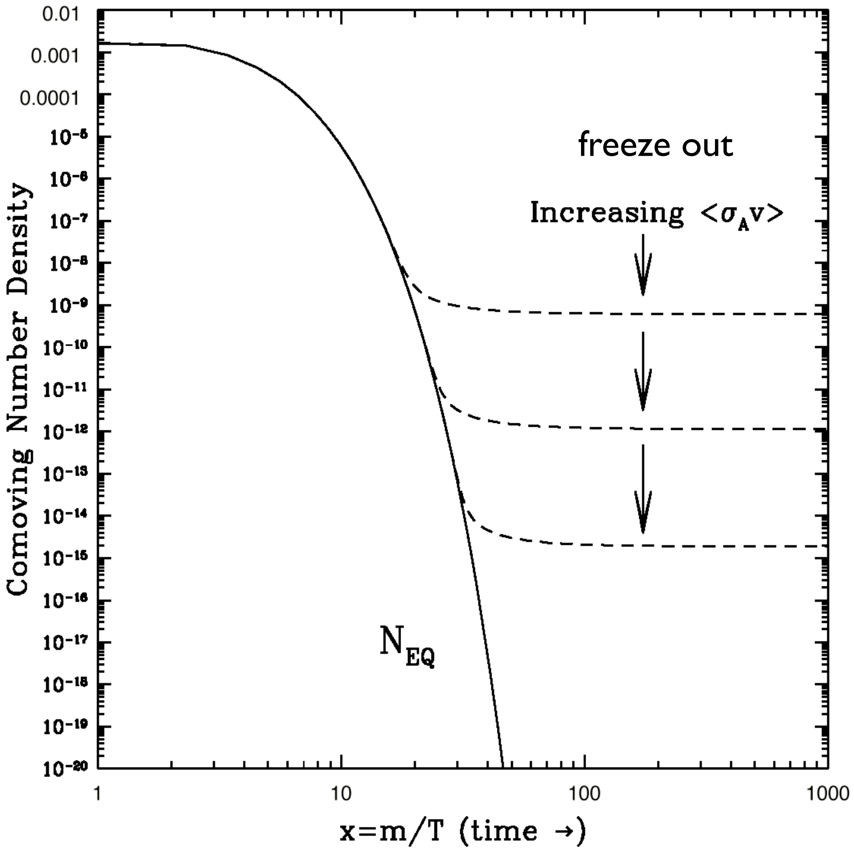
$$H > \Gamma_{ann} \sim \frac{n_\delta}{\langle \sigma_{ann}\, v \rangle}$$

  i.e., if annihilation too slow to keep up with Hubble expansion
- Leaves a relic abundance:

$$\Omega_\delta\, h^2 \approx \frac{10^{-27}}{\langle \sigma_{ann}\, v \rangle_{fr}}\ \mathrm{cm}^3\,\mathrm{s}^{-1}$$

  for m_δ = O(100 GeV)
  → if m_δ and σ_{ann} determined by new weak-scale physics, then Ω_δ is O(1)

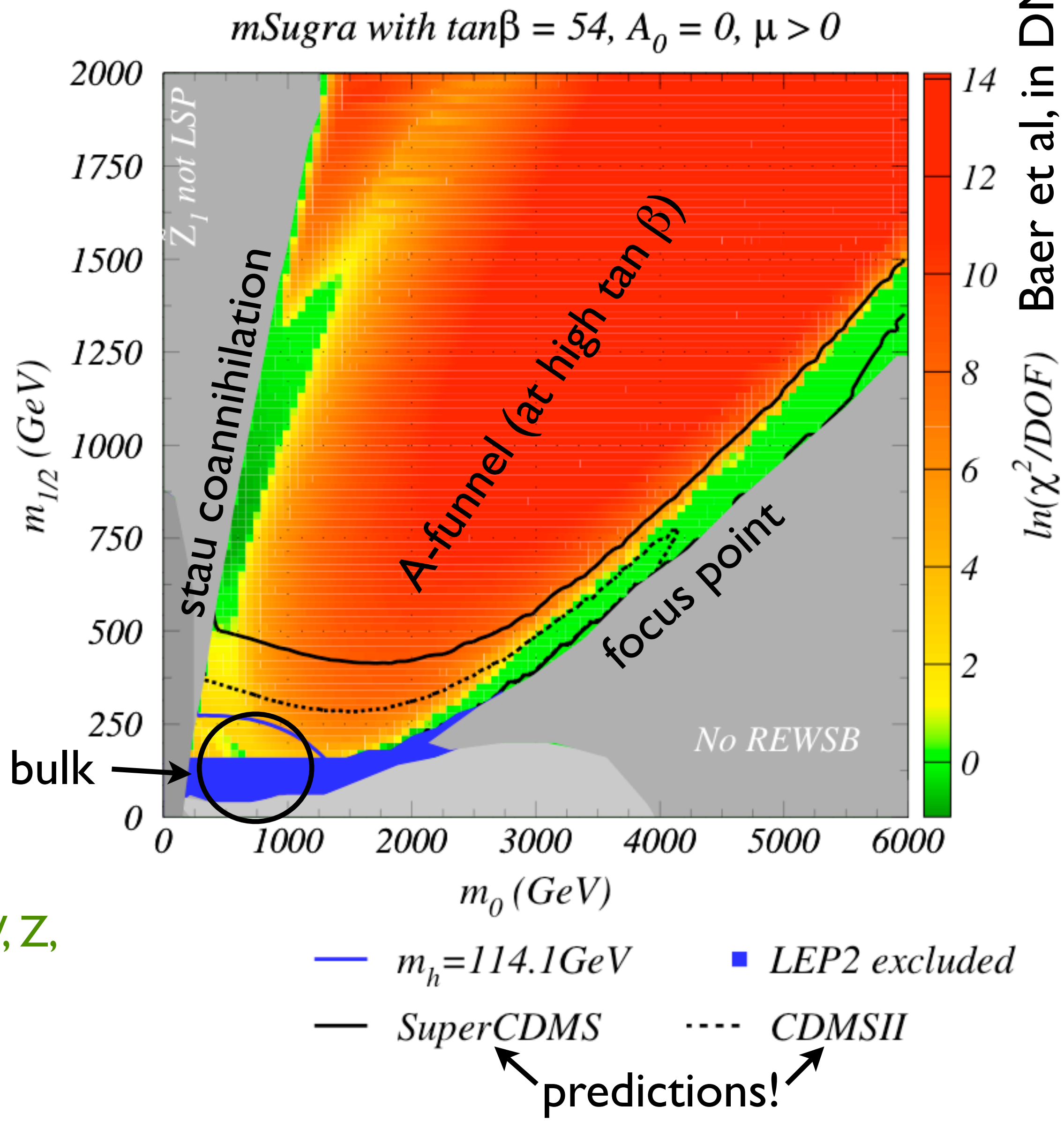
canonical Kolb and Turner freeze-out plot



Supersymmetric WIMPs

- Supersymmetry:
  - solves gauge hierarchy problem
  - improves coupling unification
- Neutralino LSP δ
  - mixture of bino, wino, higgsinos; spin 1/2 Majorana particle
  - Allowed regions
    - bulk: δ annih. via t-ch. slepton exchange, light h, high BR(b→sγ) and $(g\text{-}2)_\mu$; good DD rates
    - stau coann: δ and stau nearly degenerate, enhances annih., low DD rates
    - focus point: less fine-tuning of REWSB, δ acquires higgsino component, increases annih. to W, Z, good DD rates
    - A-funnel: at high tan β, resonant s-ch. annih. via A, low DD rates

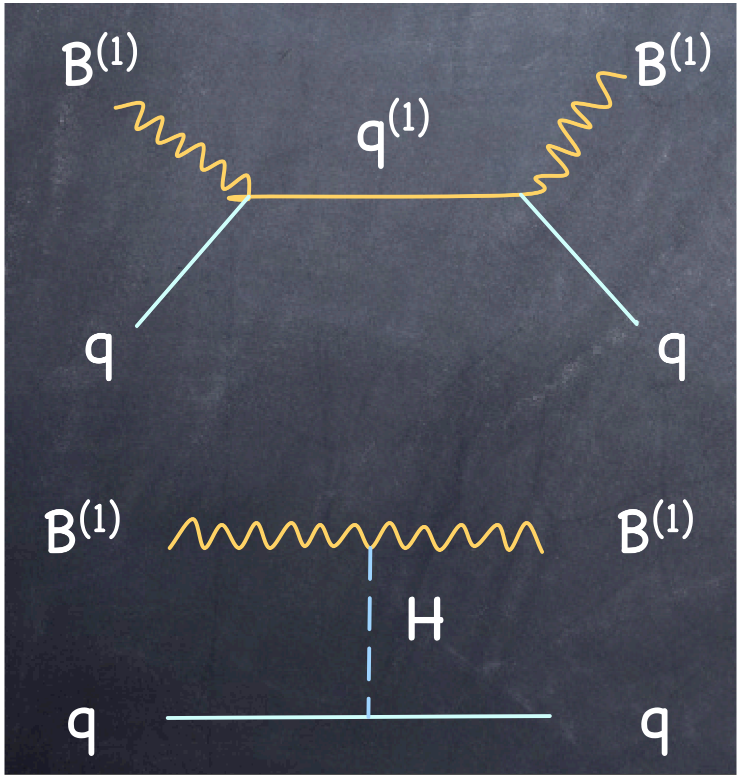
χ^2 of fit to BR(b→sγ), muon g-2, and relic density (dominated by relic density: avoid overclosure)



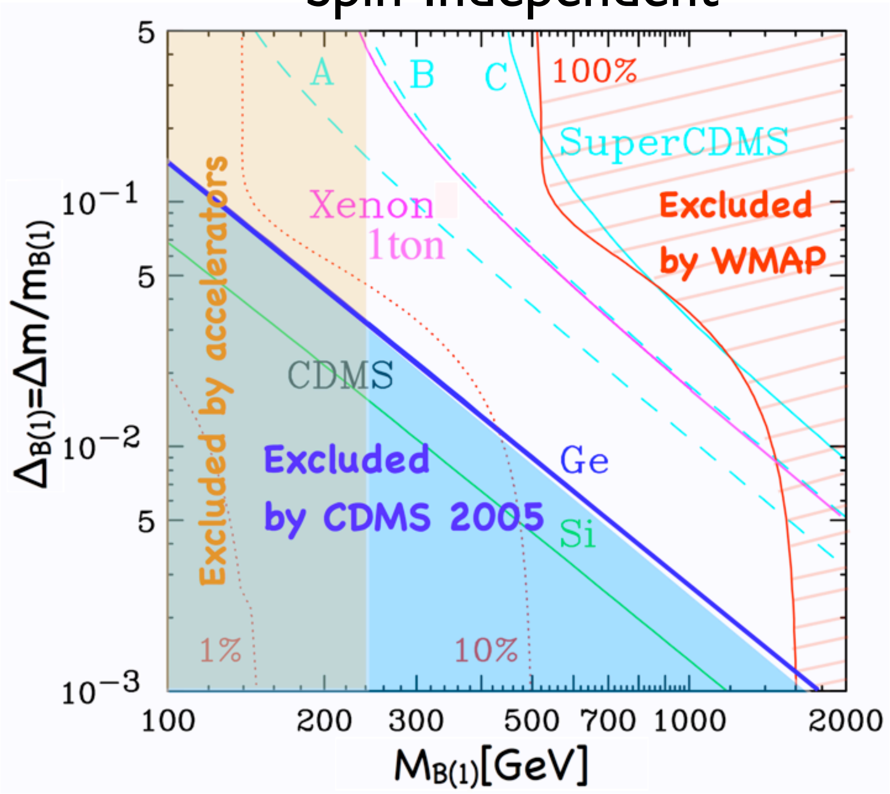
Baer et al, in DMSAG report

Universal Extra Dimensions WIMPs

- Kaluza-Klein tower of partners due to curled-up extra dimension of radius R
  - n = quantum number for extra dimension, $m_n^2 \sim n^2/R^2$
  - momentum cons. in extra dim. → exact cons. of KK particles (KK parity)
  - KK parity $P_{KK} = (-1)^n$ implies lightest KK partner ($n = 1$) is stable
- $B^{(1)}$, $n = 1$ partner of B gauge boson, is lightest KK partner in simple cases
- Cross-section on quarks depends on fractional mass difference between $B^{(1)}$ and 1st KK partner of quarks, $q^{(1)}$



Spin-Independent



Baudis, Kong, Matchev

Direct Detection: Signature

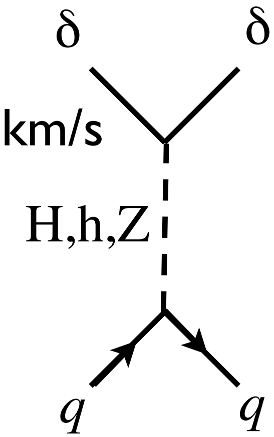
- WIMPs collected in spherical isothermal halo: ideal gas with gravity, $kT = \langle mv^2/2 \rangle$, $\sqrt{\langle v^2 \rangle} \approx 270$ km/s
- WIMPs elastically scatter off quarks in target nuclei, producing nuclear recoils, with $\sigma_{q\delta}$ related to σ_{ann} (same diagrams: via Z, h, H, and squarks)
- Energy spectrum of recoils is exponential, $\langle E_R \rangle \sim 50$ keV, depends on WIMP and target masses: Boltzmann distribution (spherical isothermal halo) + NR s-wave scattering

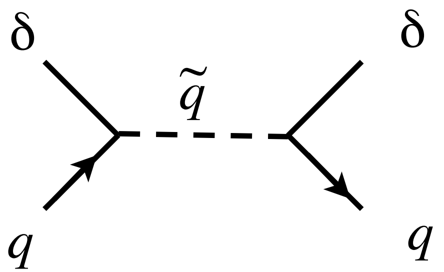
$$E_0 = \frac{2\, m_\delta^2\, m_N}{(m_\delta + m_N)^2}\, v_0^2 \approx \frac{m_N}{10^6} \sim 50\ \mathrm{keV}$$

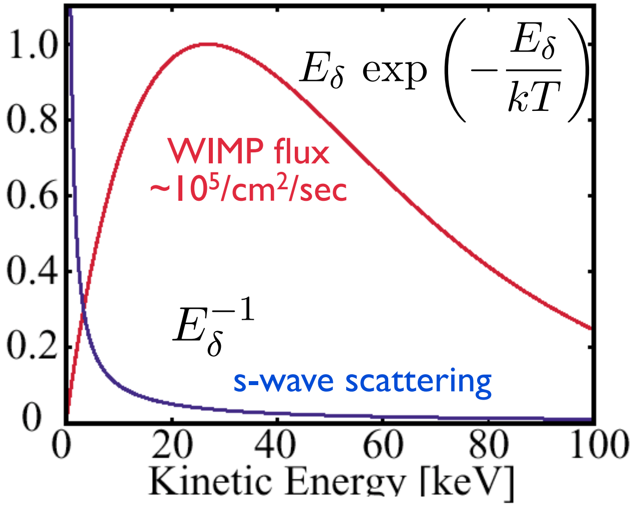
- Amplitude of recoil energy spectrum, i.e. event rate, normalized by $\sigma_{n\delta}$, local WIMP number density, and nucleus-dependent $A^2F^2(E_R)$:

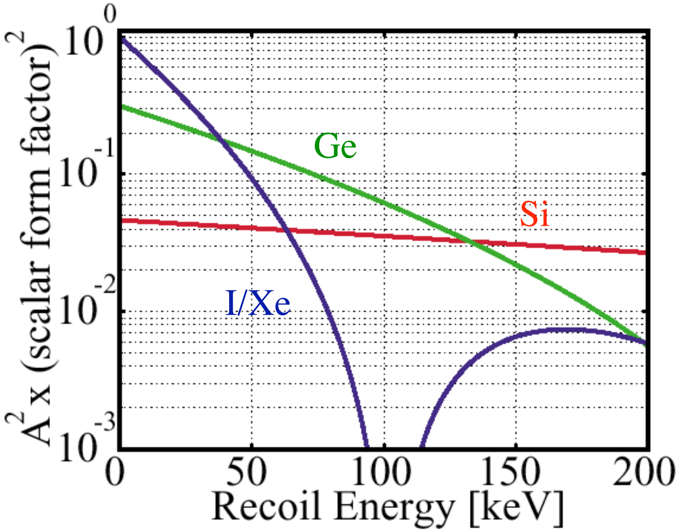
$$\frac{dR}{dE_R} \propto \frac{n_\delta\, \sigma_{n\delta}}{E_0} \exp\left(-\frac{E_R}{E_0}\right) A^2\, F^2(E_R)$$

- At low E_R, scattering is coherent and $\propto A^2$. Coherence lost at larger E_R via form factor $F^2(E_R)$







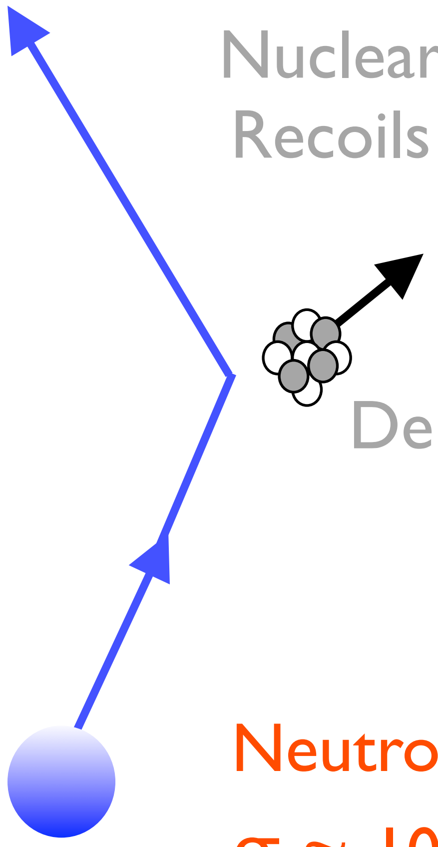


Direct Detection Experiments

- Fundamental goal: See a very small rate of WIMP interactions with nuclei in presence of many other particles interacting in detectors (photons, electrons, alpha particles, neutrons)
- Many different techniques in use today:
  - Reduce backgrounds + annual modulation
    - DAMA: NaI scintillator, KIMS: CsI scintillator
  - Event-by-event nuclear recoil discrimination
    - phonons + ionization/scintillation: CDMS, EDELWEISS, CRESST, ROSEBUD
    - Liquid Nobles: scintillation + ionization and/or pulse-shape: XENON, LUX, ZEPLIN, WArP, ArDM, DEAP, CLEAN, etc.
    - Superheated droplets: bgnd-insensitive threshold detectors: COUPP, PICASSO
    - Gaseous time projection chambers: DRIFT, DMTPC
  - Diurnal modulation
    - Gaseous time projection chambers: DRIFT, DMTPC

Nuclear Recoil Discrimination

Signal



Nuclear Recoils

E_r

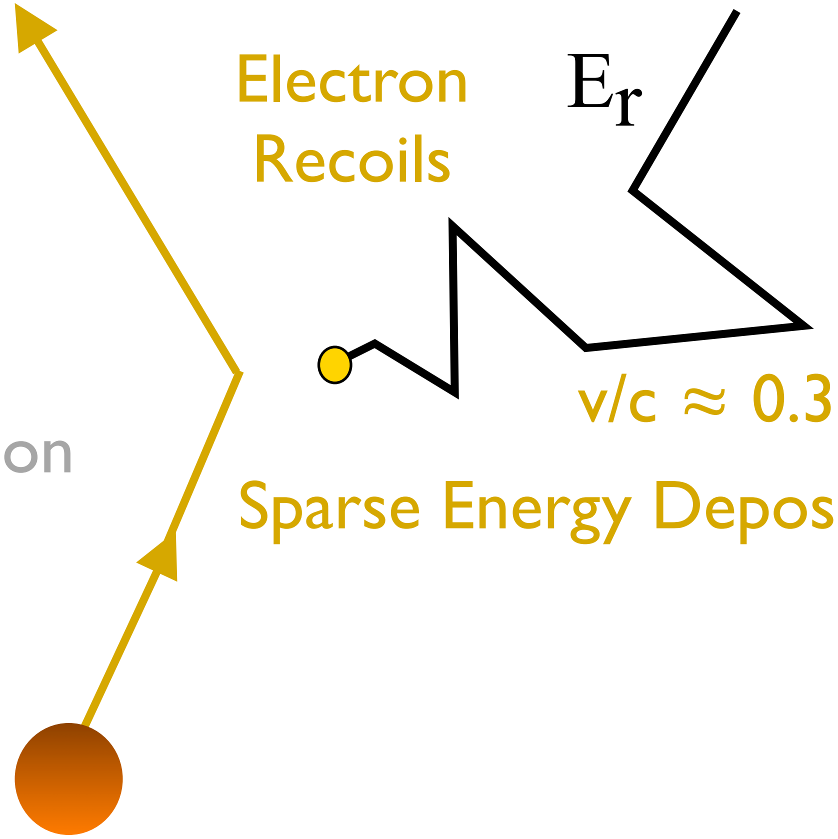
v/c ≈ 10^{-3}

Dense Energy Deposition

δ

Neutrons same, but
$\sigma \approx 10^{20}$ higher;
must shield
(go deep underground)

Background



Electron Recoils

E_r

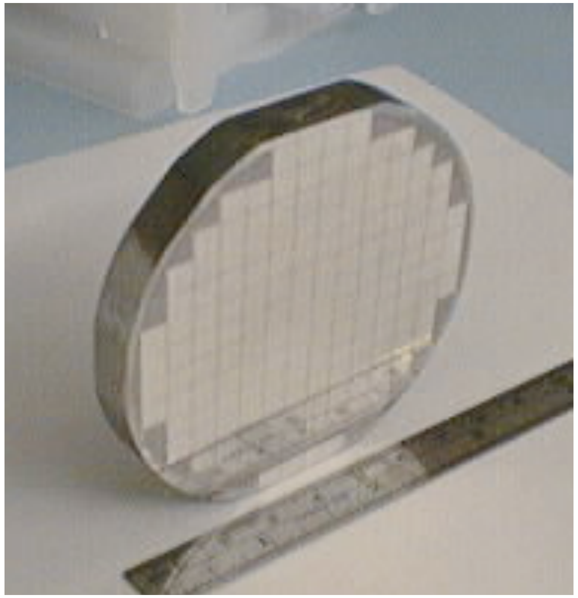
v/c ≈ 0.3

Sparse Energy Deposition

γ

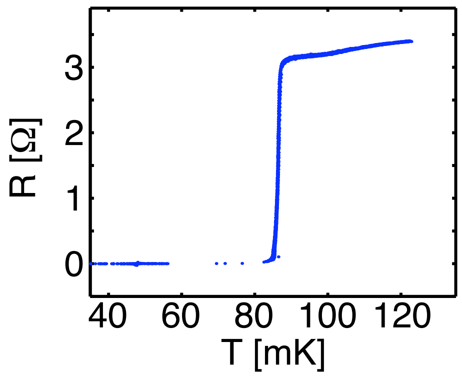
**Density/Sparsity:
Basis of Discrimination**

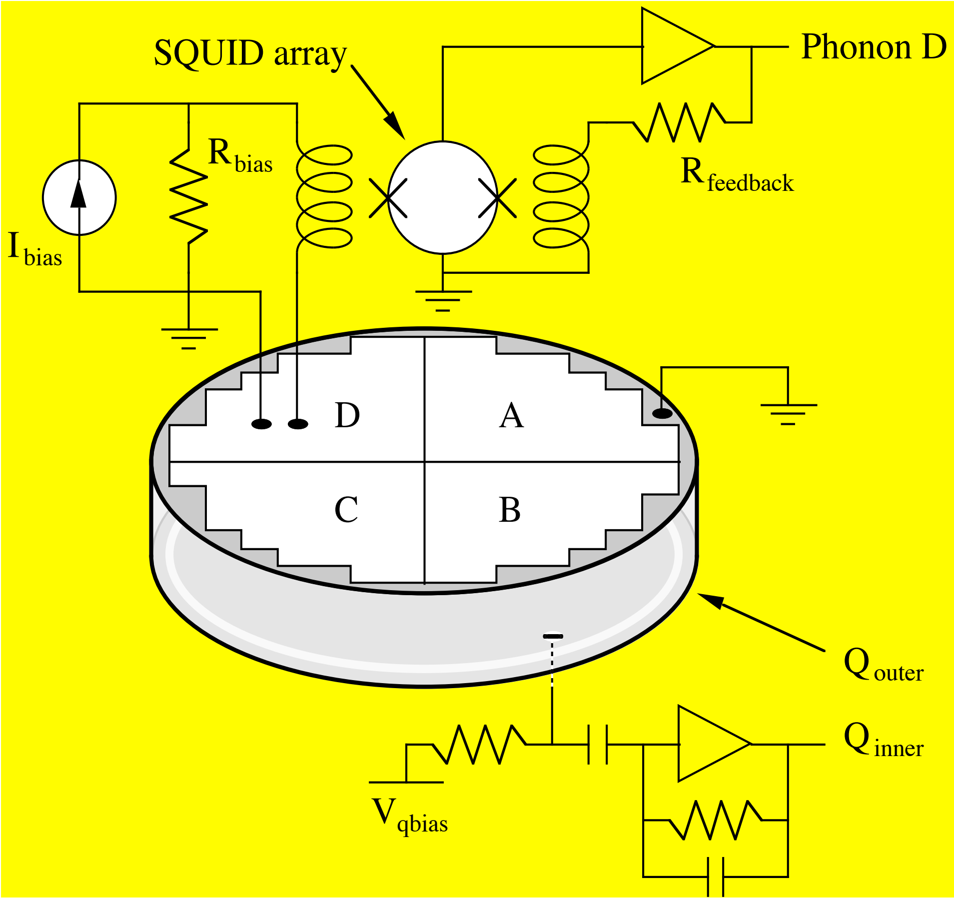
CDMS ZIP Detectors

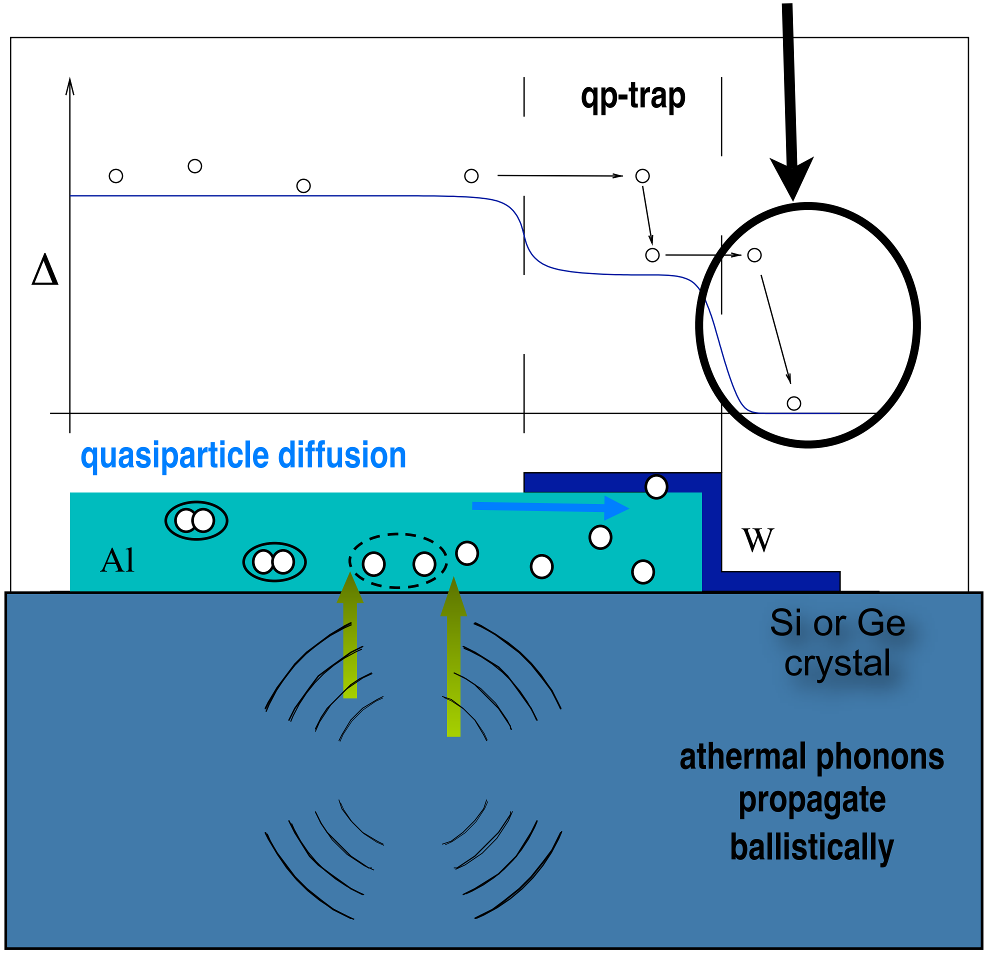


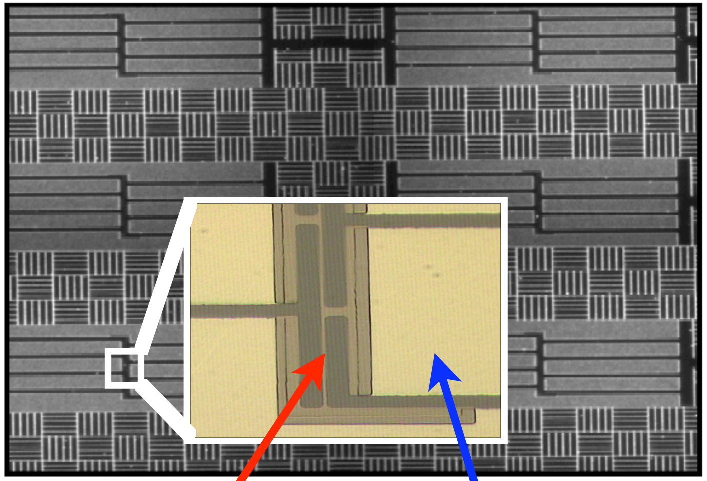
Z-sensitive Ionization- and Phonon-mediated detectors: Phonon signal measured using photolithographed superconducting phonon absorbers and transition-edge sensors.

TES = transition edge sensor









1 μm tungsten TES

380 μm x 60 μm aluminum fins

CDMS ZIP Detectors

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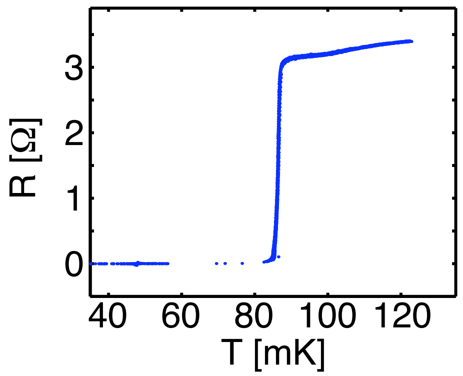

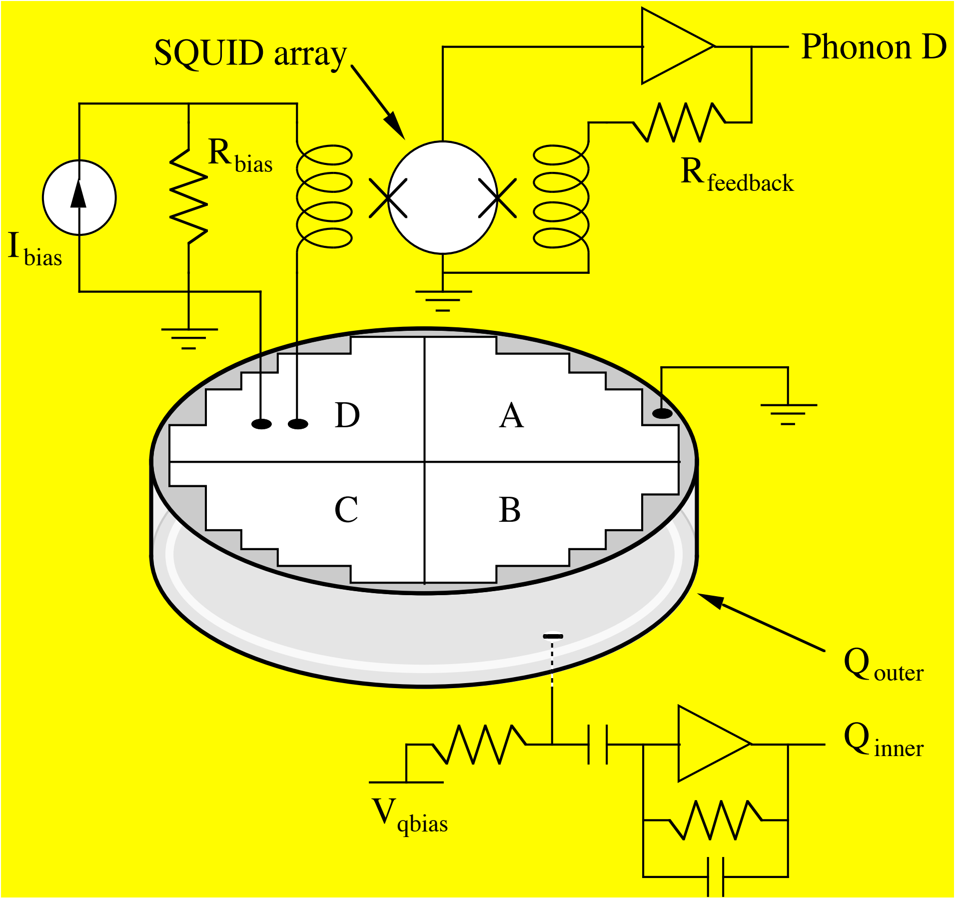

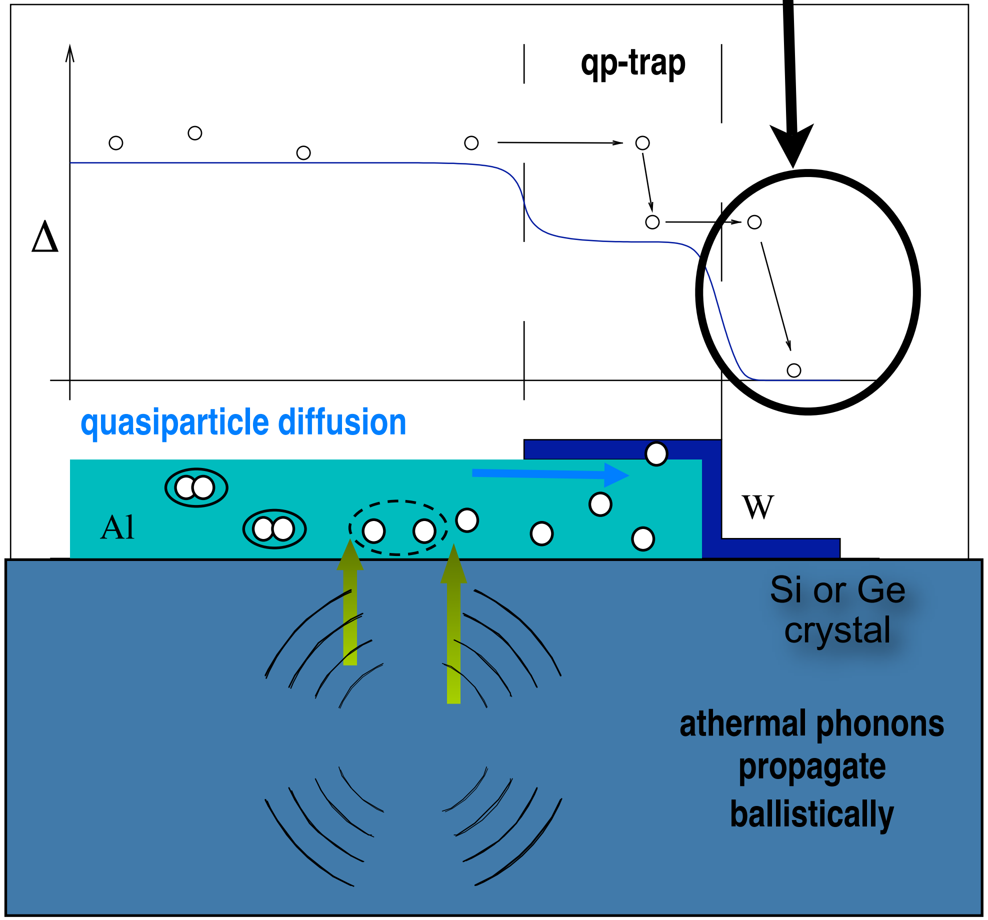

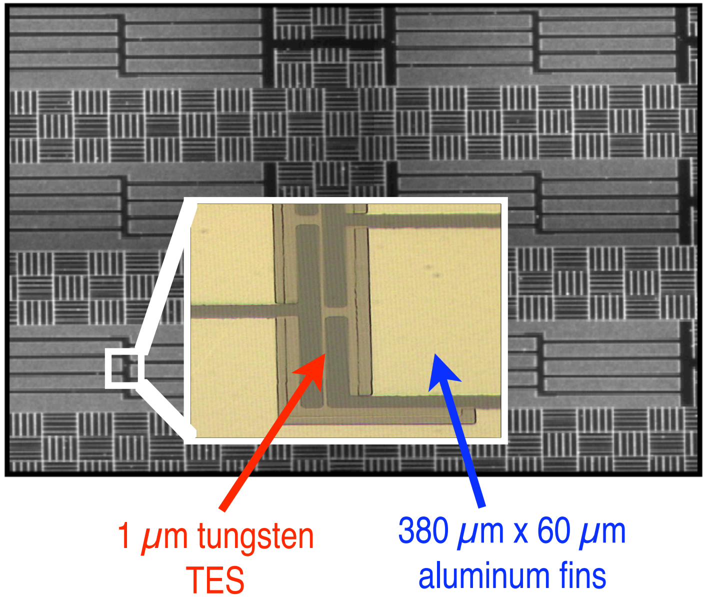

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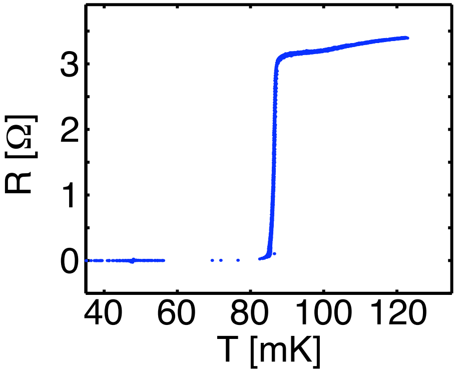
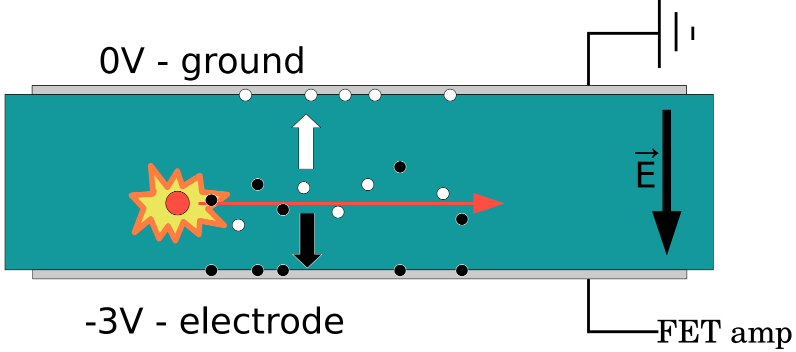
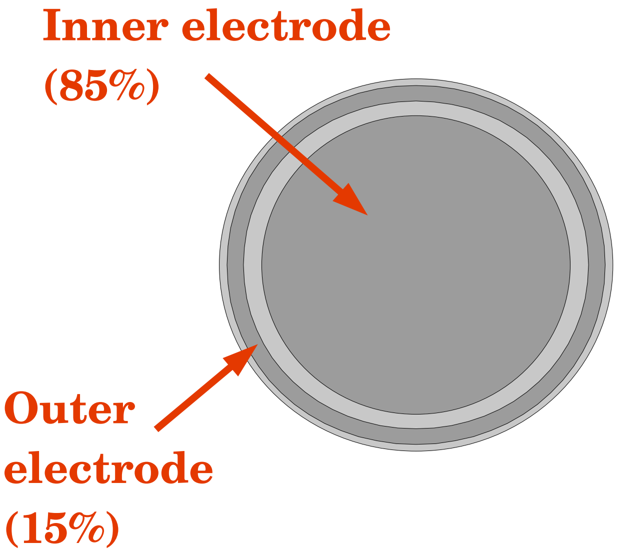
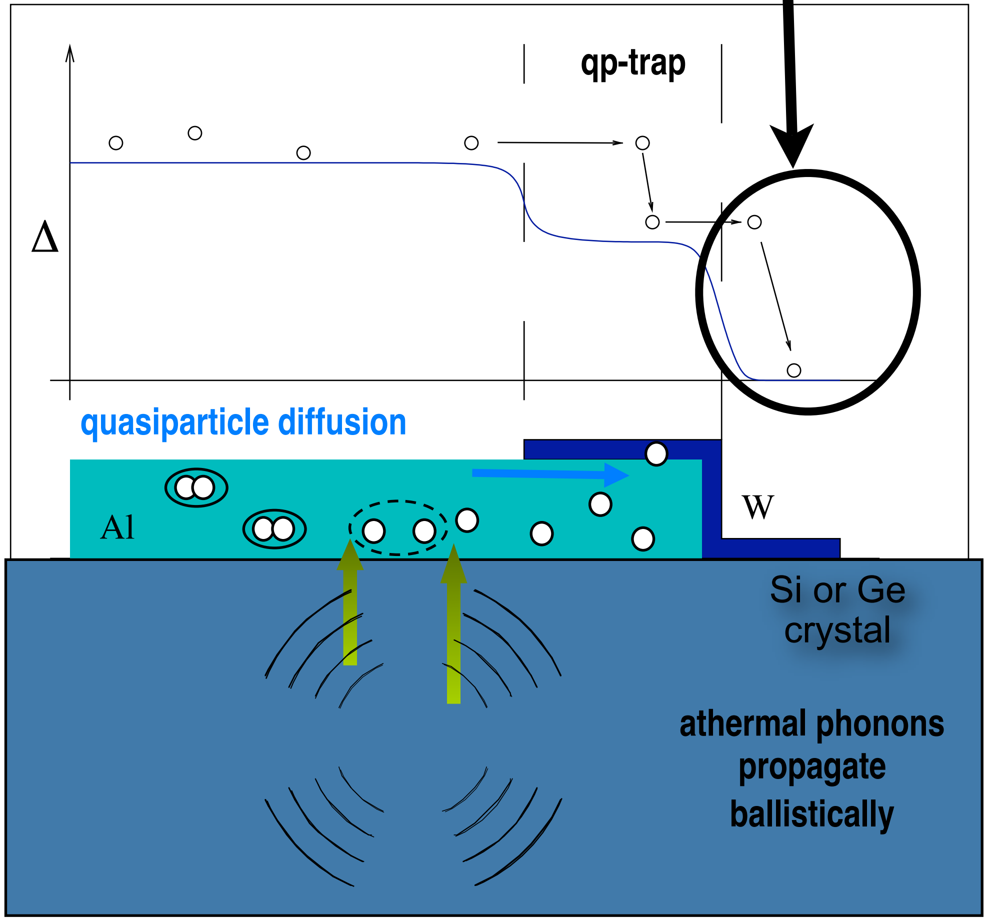
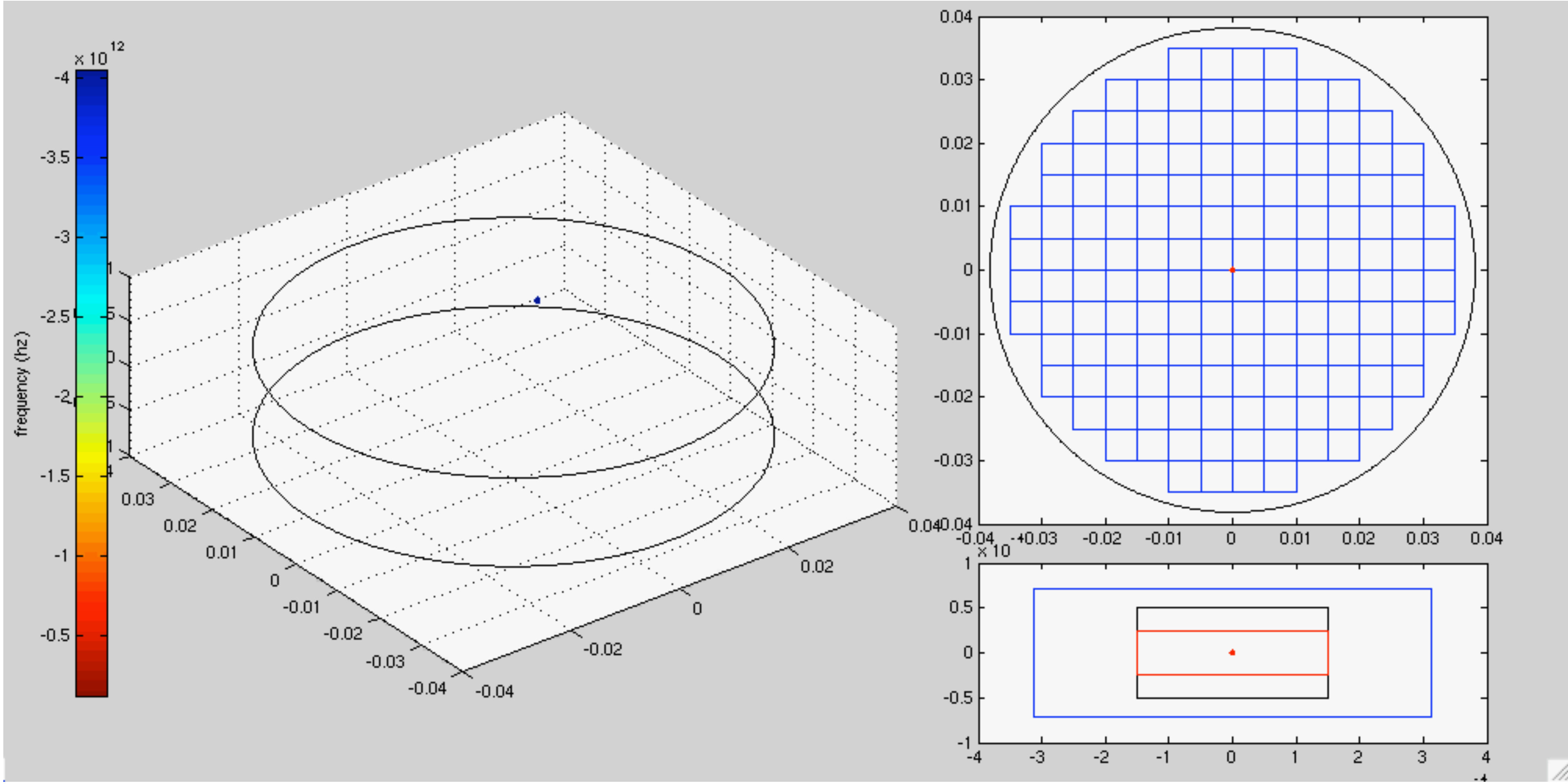






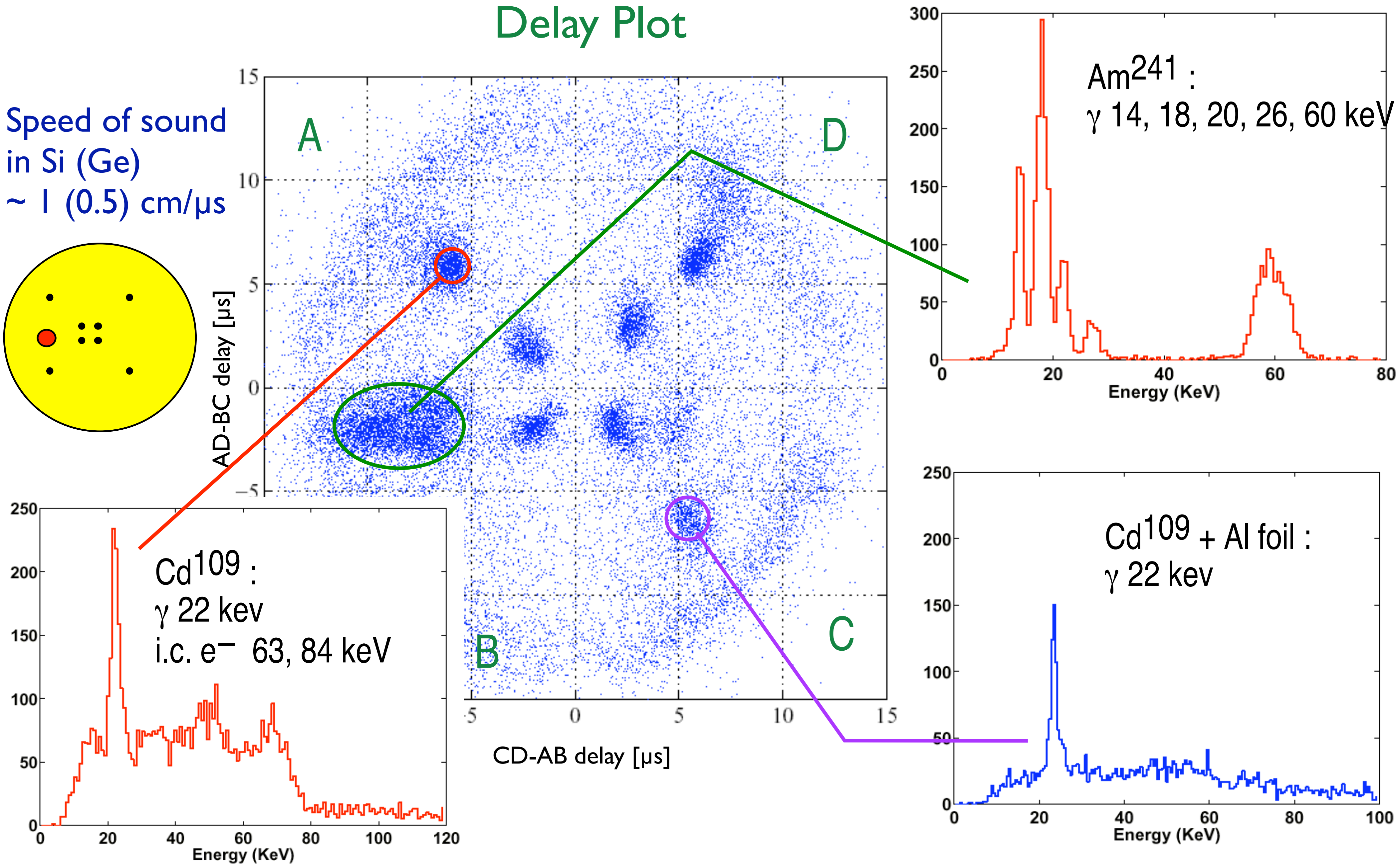


ZIP Detectors



ZIP xy Position Sensitivity

Speed of sound in Si (Ge)
~ 1 (0.5) cm/μs

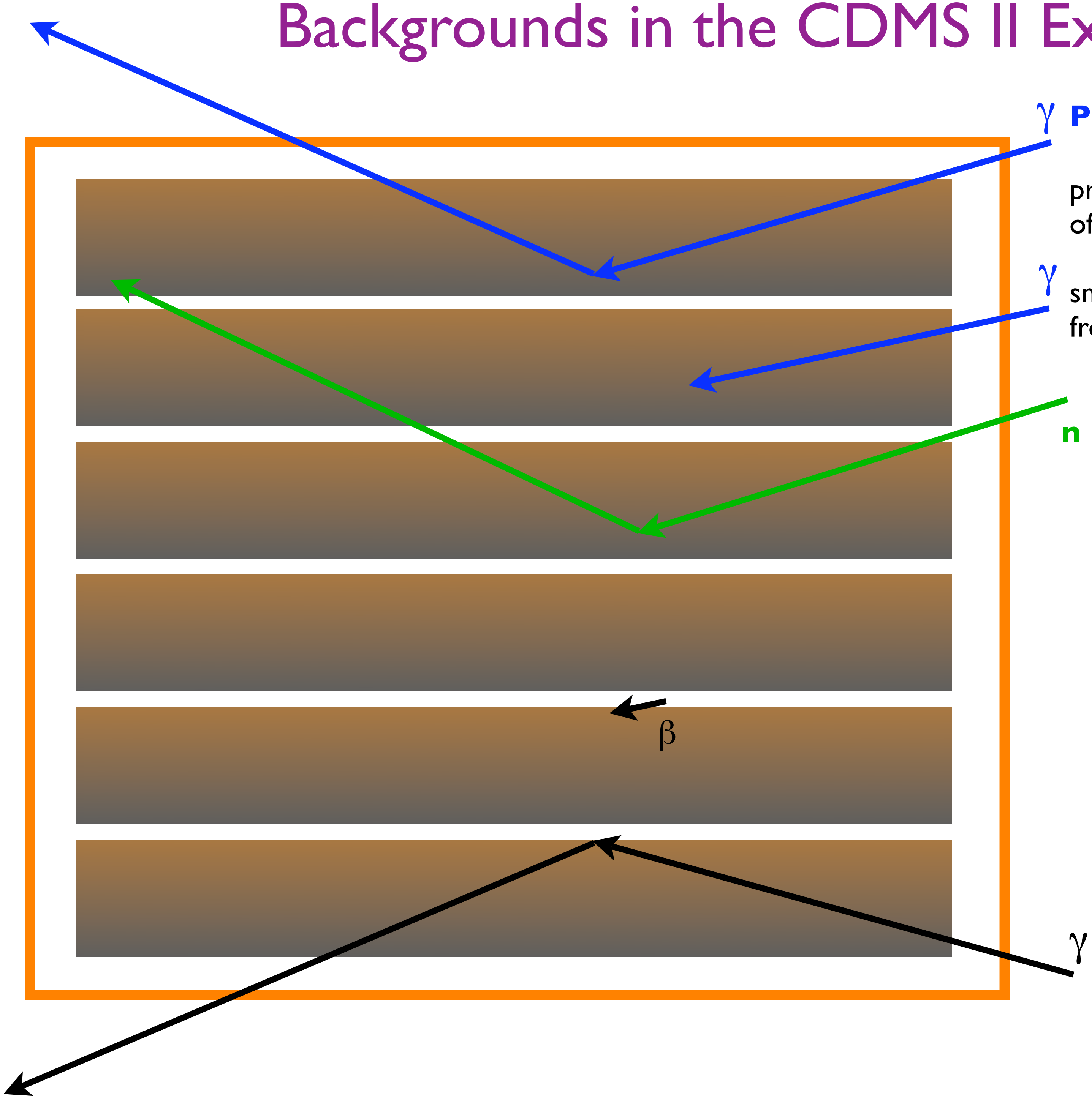


Am^{241} :
γ 14, 18, 20, 26, 60 keV

Cd^{109} :
γ 22 kev
i.c. e^{-} 63, 84 keV

Cd^{109} + Al foil :
γ 22 kev

Backgrounds in the CDMS II Experiment



Photons (γ)

primarily Compton scattering
of broad spectrum up to 2.5 MeV

small amount of photoelectric effect
from low energy gammas

Neutrons (n)

radiogenic: arising from fission and (α,n) reactions in surrounding materials (cryostat, shield, cavern)

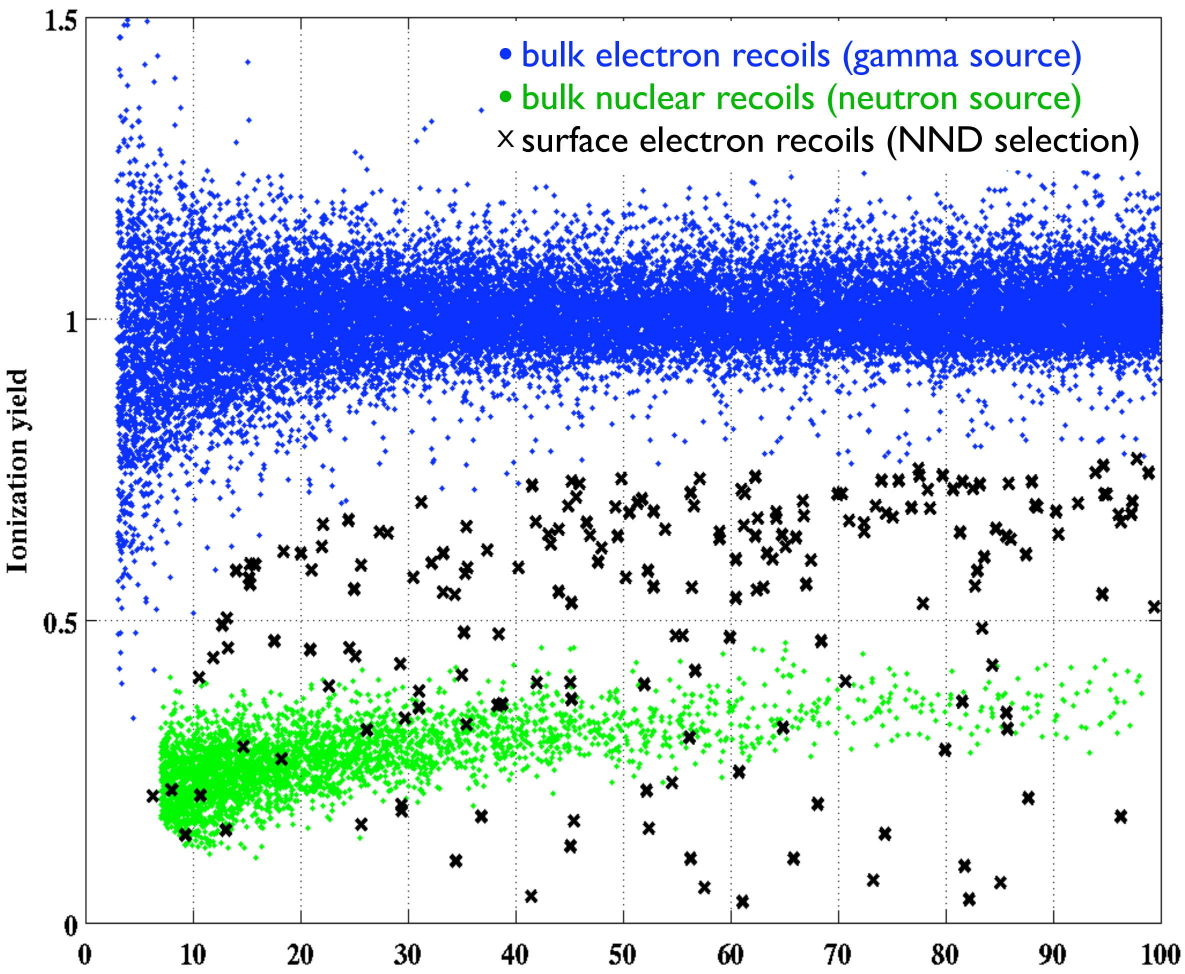
cosmogenic: created by spallation of nuclei in surround materials by high-energy cosmic ray muons.

Surface events (“β”)

radiogenic: electrons/photons emitted in low-energy beta decays of ^{210}Pb or other surface contaminants

photon-induced: interactions of photons or photo-ejected electrons in dead layer

Nuclear Recoil Discrimination in CDMS II

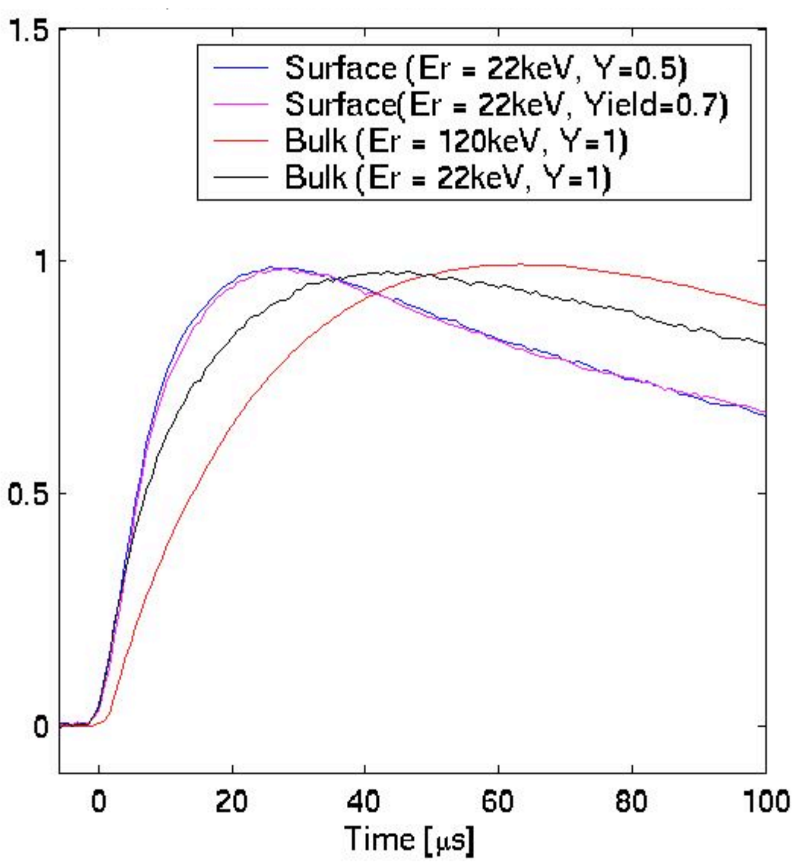


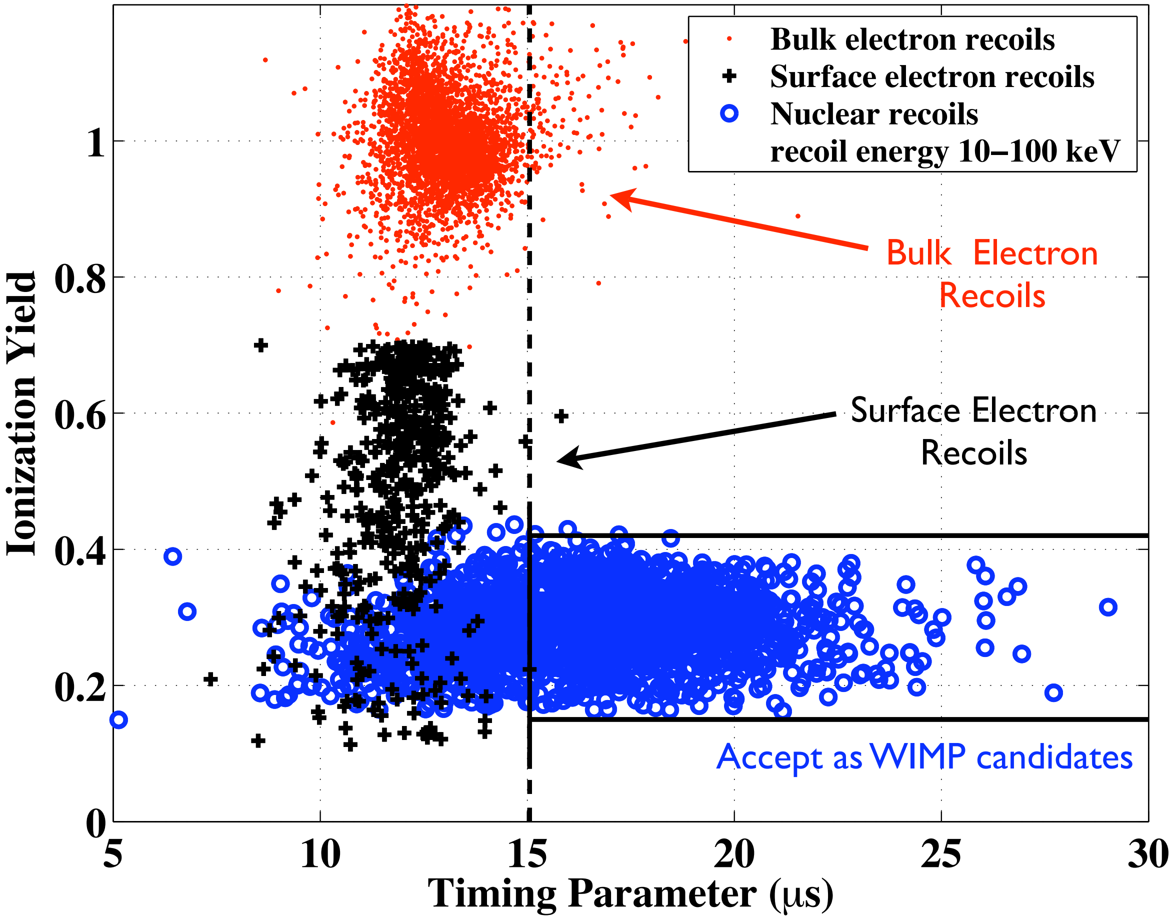
- Recoil energy
  - Phonon (acoustic vibrations, heat) measurements give full recoil energy
- Ionization yield
  - ionization/recoil energy strongly dependent on type of recoil (Lindhard)
- Excellent yield-based discrimination for photons
  - 2 x 10^{-4} misid
- Ionization dead layer:
  - low-energy electron singles (all surface ER): 0.2 misid
  - 1.2 x 10^{-3} of photons are surface single scatters, 0.2 of those misid'd ($\Rightarrow$ 2 x 10^{-4})
- But, phonon timing identifies surface events w/ < 0.006 misid, giving
  - Photons: < 2 x 10^{-6} misid

ZIP z Position Sensitivity

- Surface events produce faster phonon pulses (test sample: nearest neighbor low-yield doubles (NNDs))
- overall misidentification: $< 2 \times 10^{-6}$ for photons, $< 2 \times 10^{-3}$ for electrons

1:1 scale: 3 in. x 1 cm, 1 mm separation





Bulk Electron Recoils

Surface Electron Recoils

Accept as WIMP candidates

ZIP z Position Sensitivity

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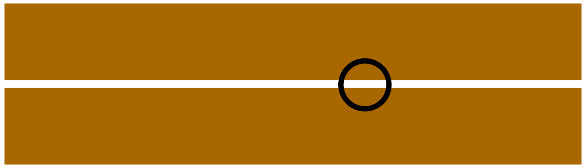
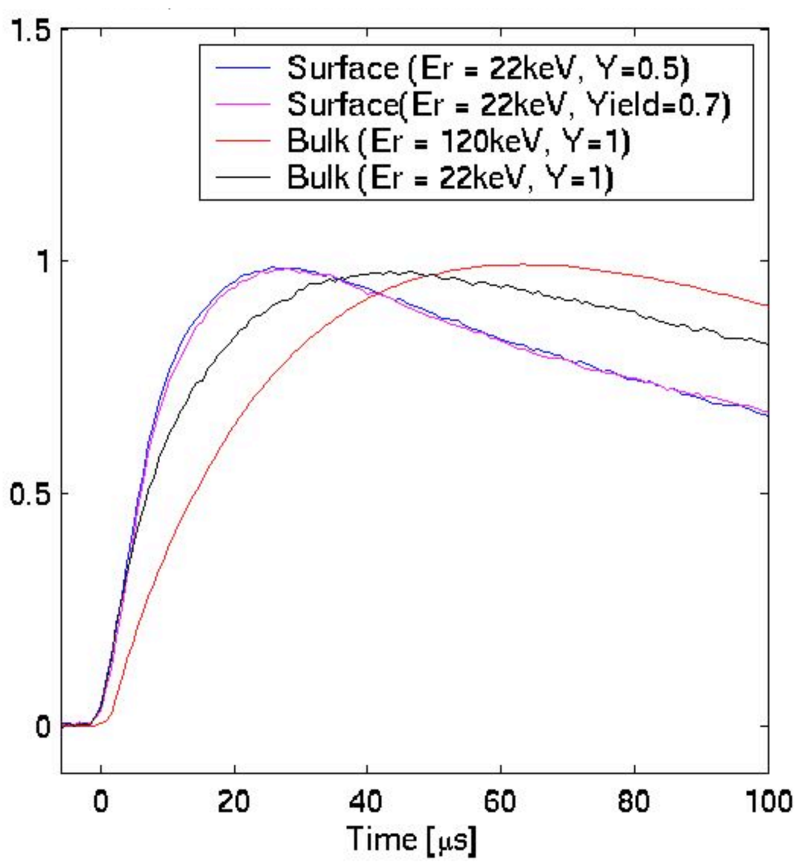
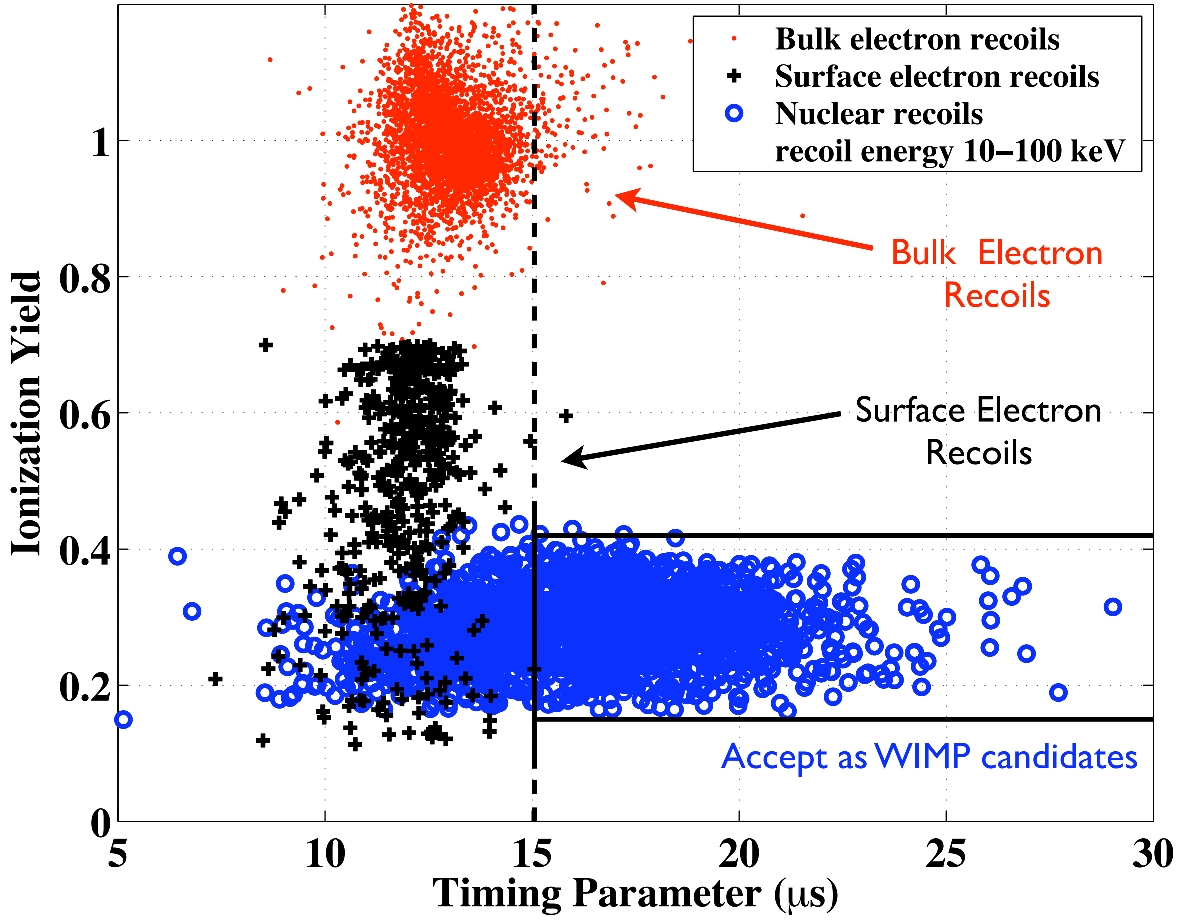


1:1 scale: 3 in. x 1 cm, 1 mm separation





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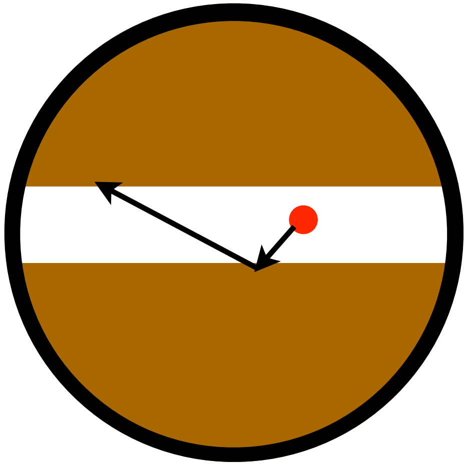
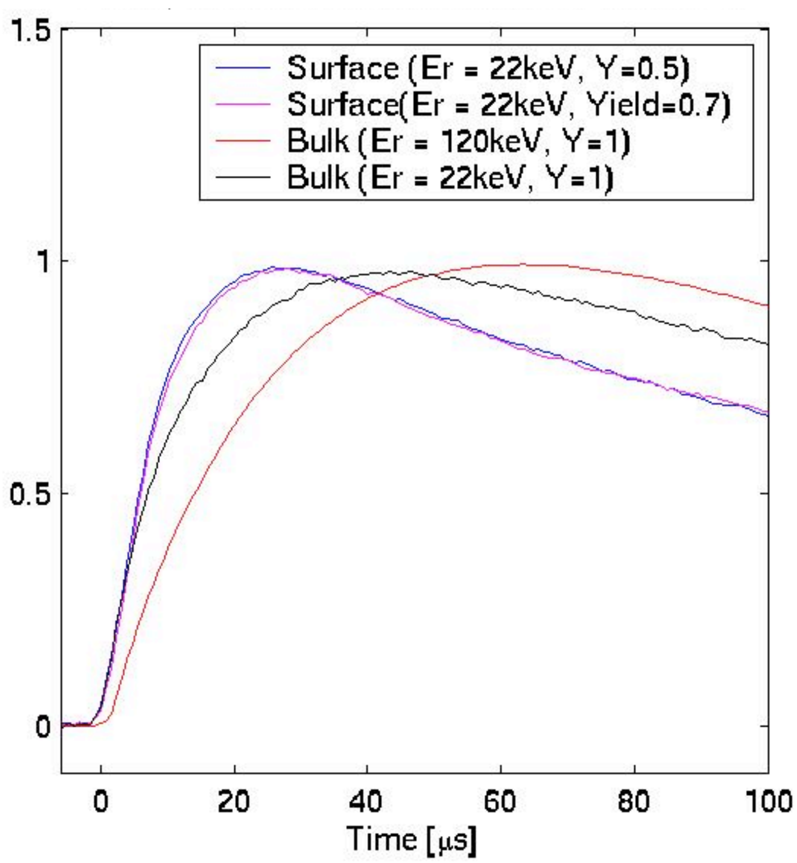
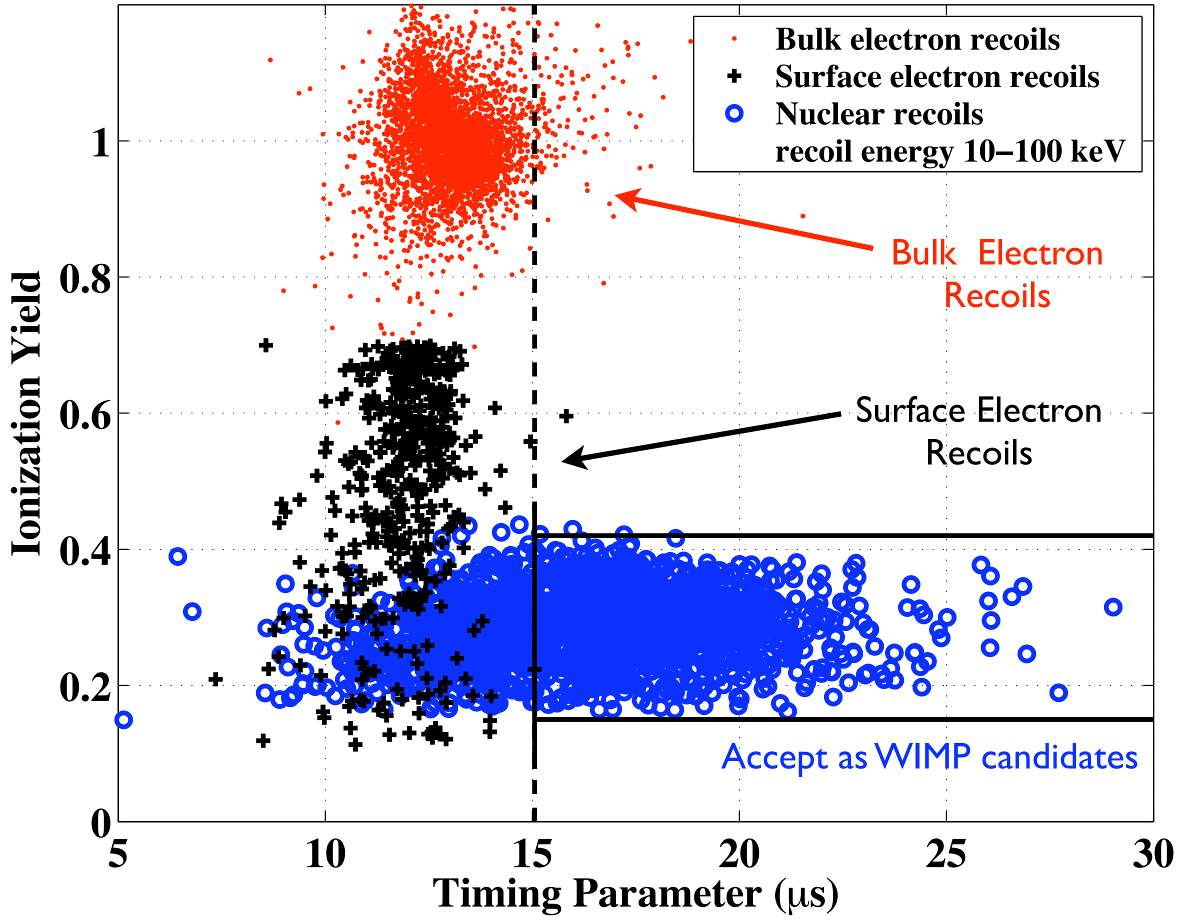
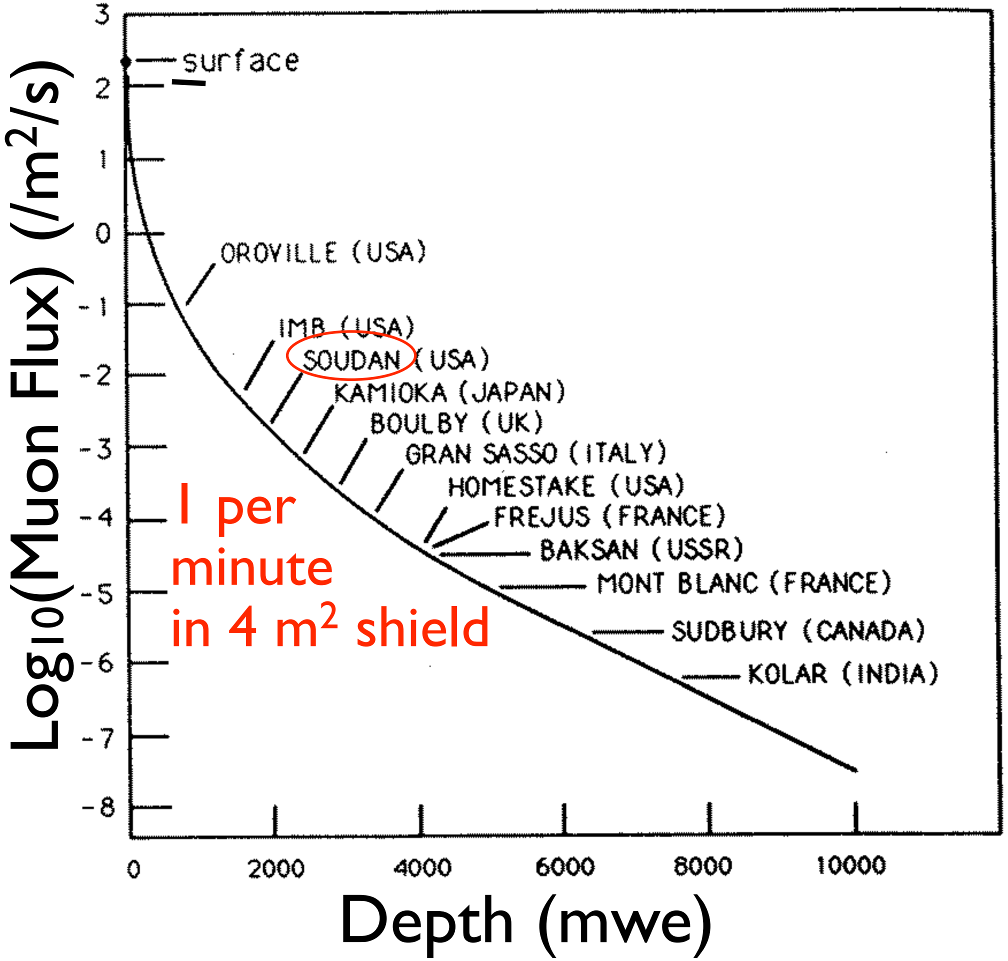






2002–2008: CDMS II at Soudan

Depth of 2000 meters water equivalent reduces neutron background to ~1 / kg / year; veto down to 0.008 sgl / kg / yr



1 per minute in 4 m^2 shield

The CDMS II/SuperCDMS/GEODM Collaborations

Brown University
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Caltech
Z. Ahmed, J. Filippini, S. R. Golwala, D. Moore, R. W. Ogburn

Case Western Reserve University
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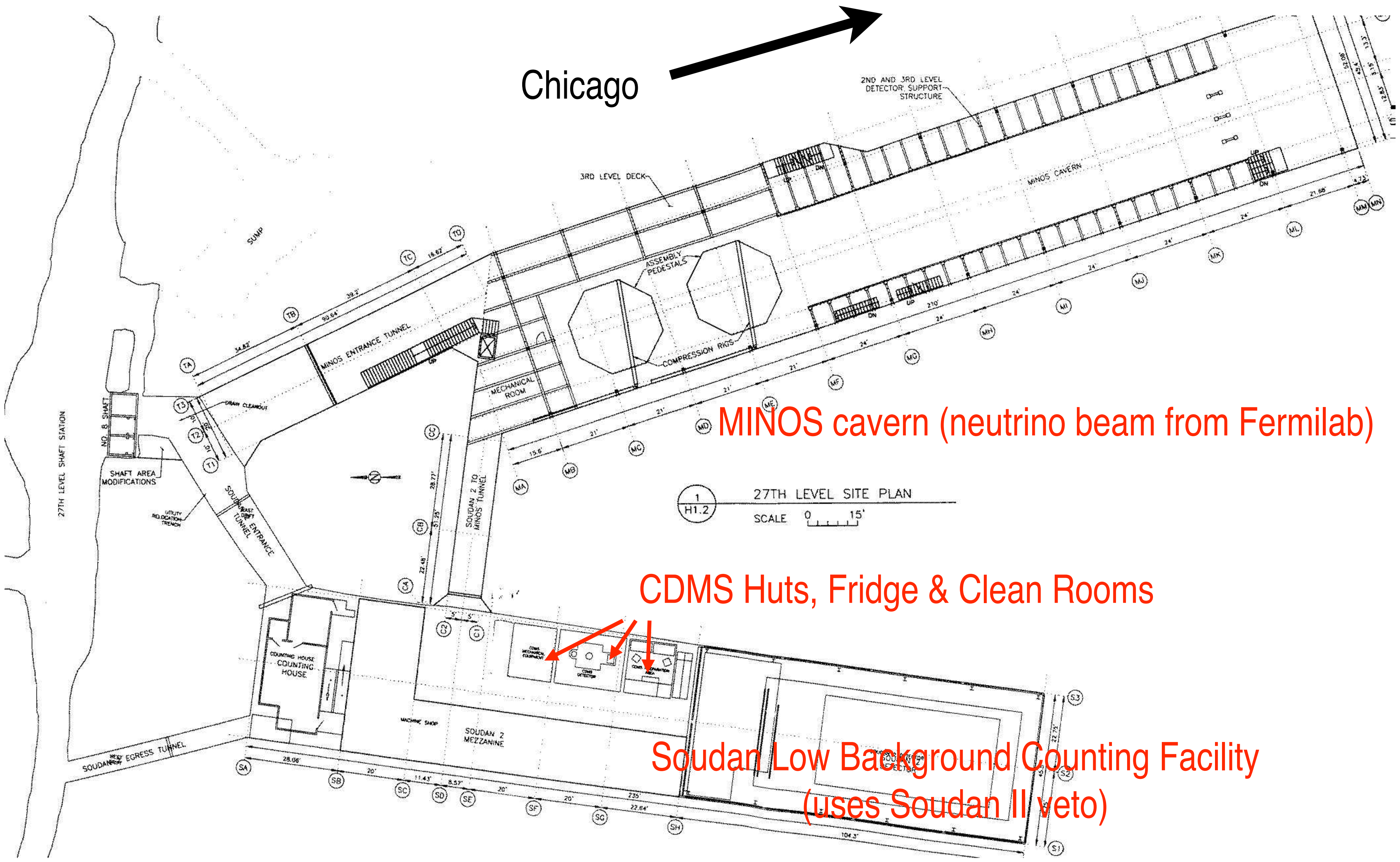
Office of Science
U.S. Department of Energy

office of high energy physics

CDMS Soudan Mine Installation



Chicago

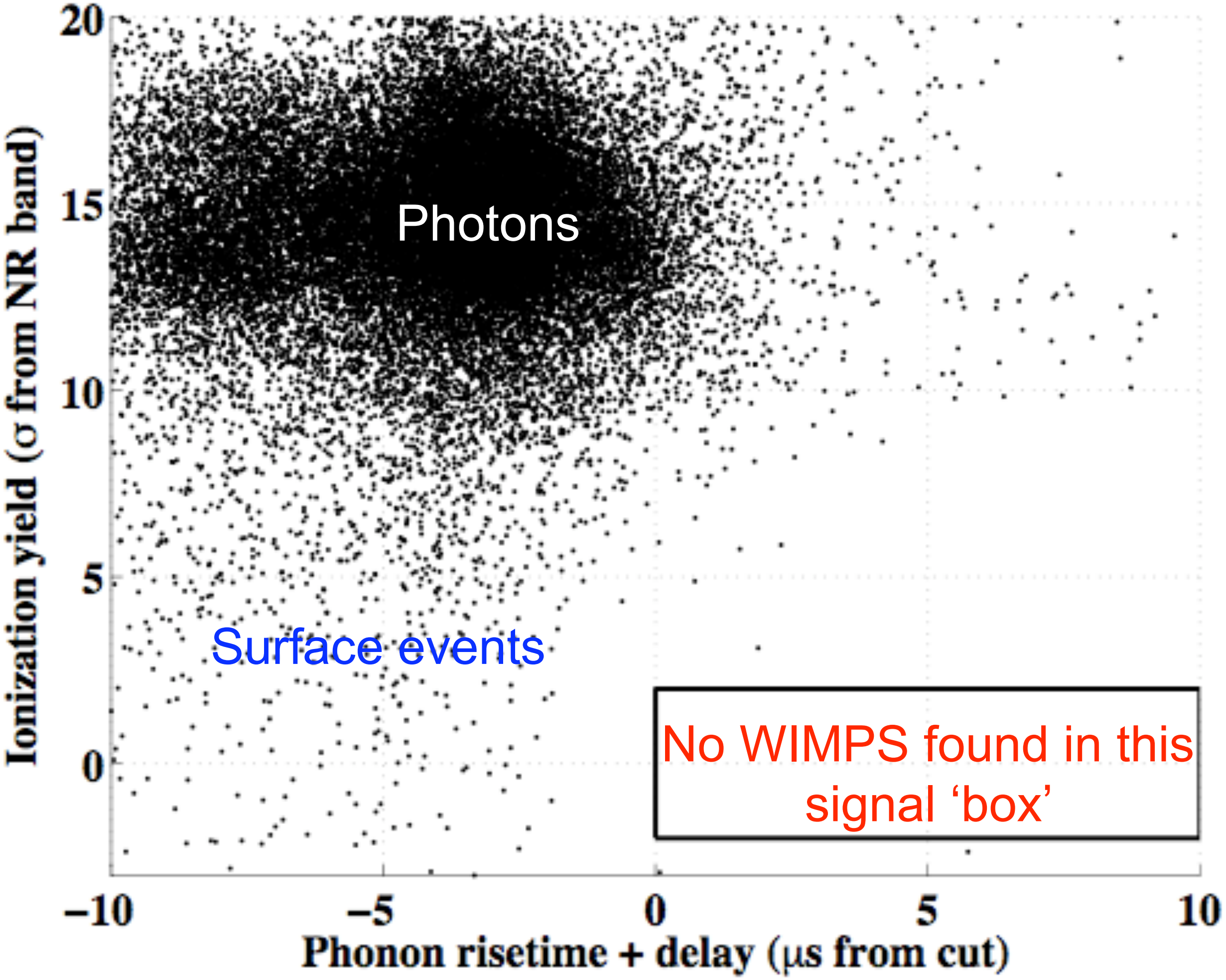
MINOS cavern (neutrino beam from Fermilab)

CDMS Huts, Fridge & Clean Rooms

Soudan Low Background Counting Facility
(uses Soudan II veto)

CDMS II 2008 Results

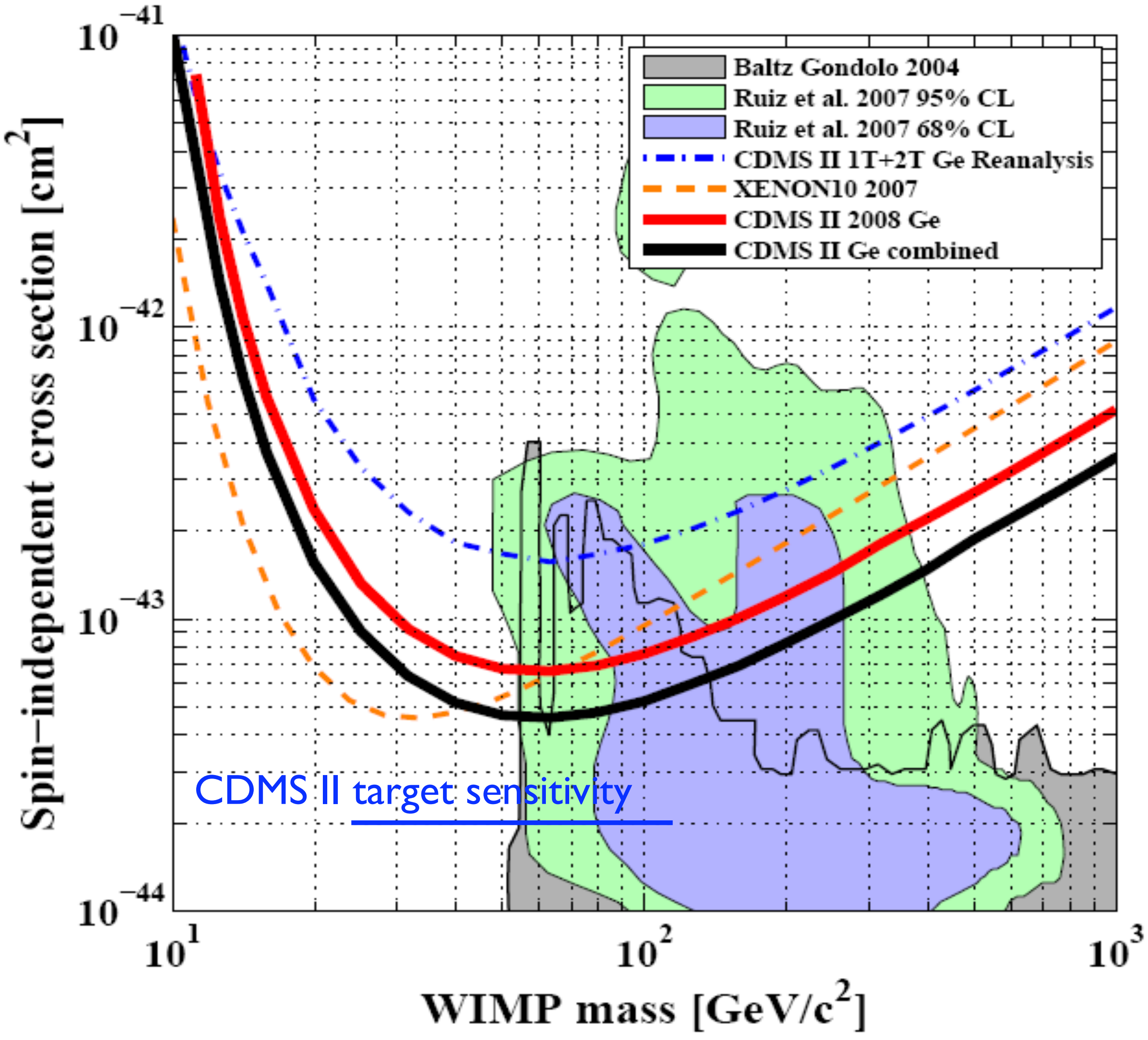
- 398 kg-d raw exposure
- Single-scatter events
- Estimated leakage of misidentified surface events determined from:
  - photon cal data
  - WIMP-search multiples
  - Cuts defined to obtain ~0.5 leakage events: optimal balance of efficiency and leakage



No WIMPS found in this signal ‘box’

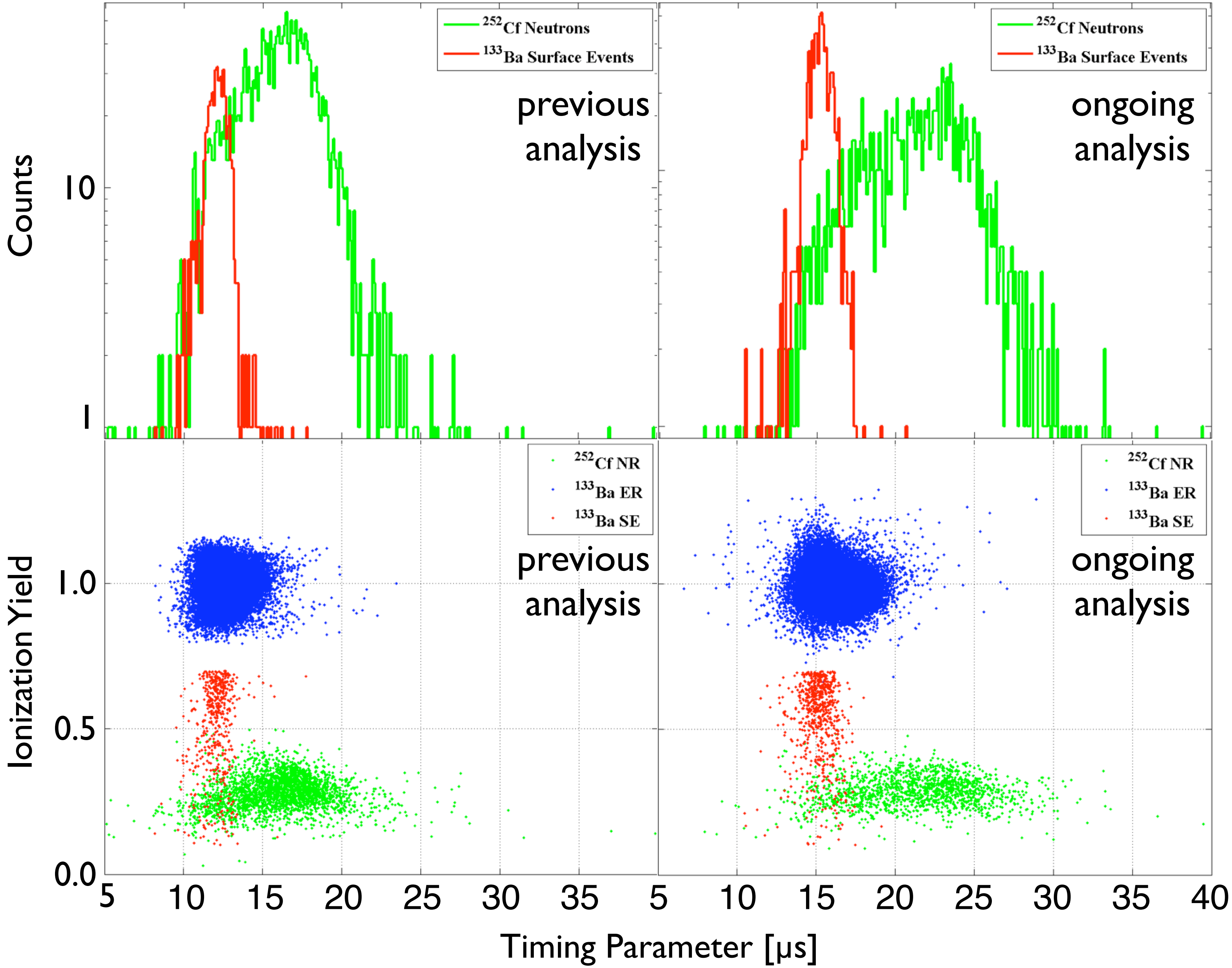
- Expect 0.6 +0.5-0.3 (stat) +0.03-0.02 (syst) misidentified surface events
- Expect < 0.1 unvetoed single-scatter neutrons (conservative)
- **0 events observed**

Spin-Independent Exclusion Limit



- Zero events observed
- Including reanalysis of prior data set, obtain best spin-independent limit for M > 40 GeV/c^2; published in PRL, Filippini thesis
- 2.5X exposure in hand and being analyzed
  - many analysis improvements
  - should reach CDMS II target sensitivity of 2×10^{-44} cm^2

Ongoing Final CDMS II Analysis



From CDMS II to SuperCDMS and GEODM

CDMS II

∅7.5cm x 1cm ZIP
0.25 kg/detector

16 detectors = 4 kg
2 yr, 1700 kg-d

SuperCDMS Soudan

∅7.5cm x 2.5cm mZIP
0.64 kg/detector

25 detectors = 15 kg
2 yr, 8000 kg-d

SuperCDMS SNOLAB

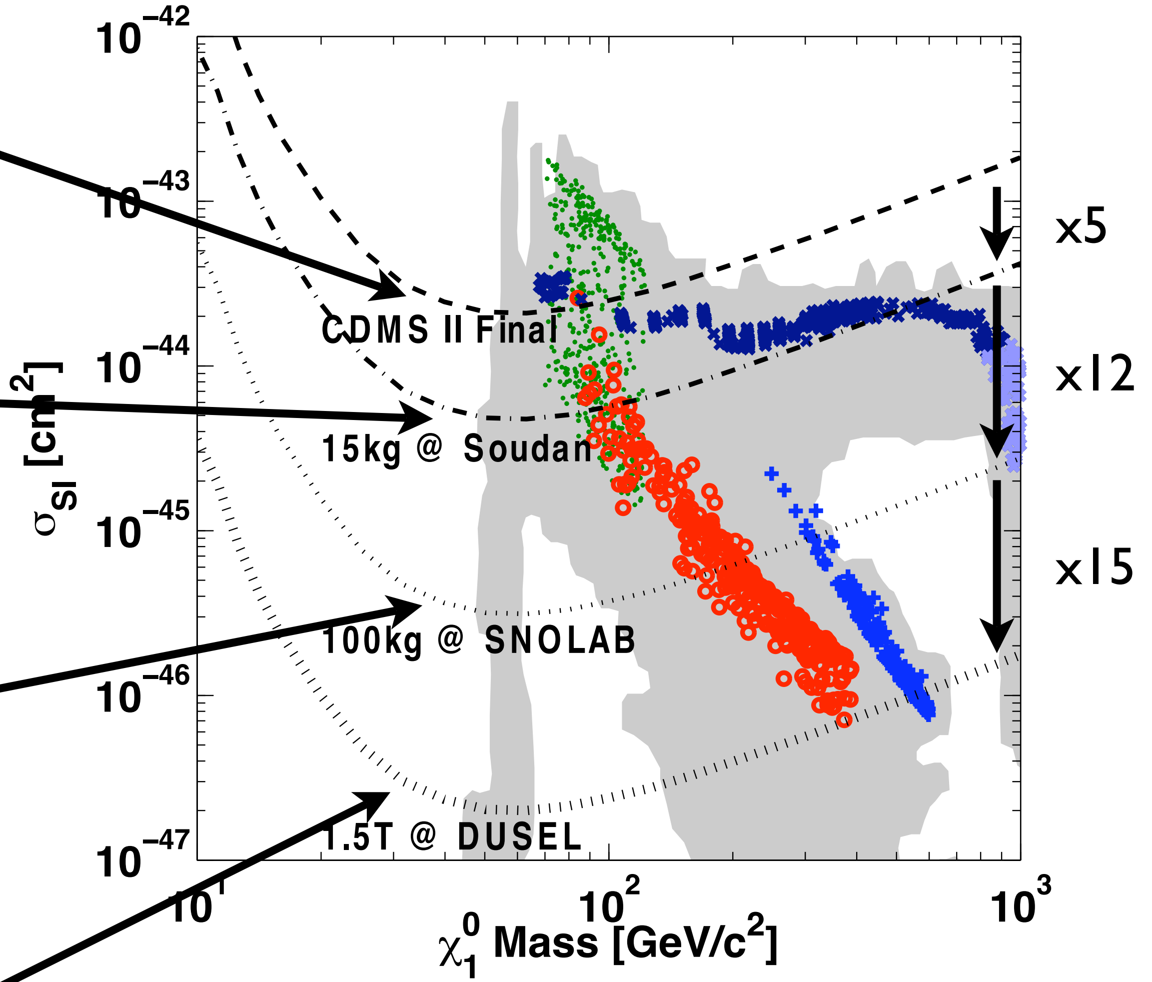
∅10cm x 3.5cm iZIP
1.5 kg/detector

70 detectors = 105 kg
3 yr = 100,000 kg-d

GEODM DUSEL

∅15cm x 5cm iZIP
5.1 kg/detector

300 detectors = 1.5 T
4 yr, 1.5 M kg-d



Staged three-prong program to explore MSSM or study a signal:

- decreased backgrounds
- improved background rejection
- increase in mass/detector and decrease in cost/detector

< 1 event misid'd bgnd at each stage

Backgrounds and Background Rejection: Photons

- Consider together bulk scattering and surface events due to photon background
  - Moderate improvements in raw rates; already shown in CDMS I
  - Moderate reductions in surface area/volume ratio via increased mass/detector
  - More significant improvements in background rejection via improved detector design (see later)

reduction of raw background rate via better shielding/reduced contamination

improvement in background rejection via better discrimination

Stage	Rate [/kg/d]	Relative Rate	Sgl. Scatter x Misid. Prob.	Relative Misid. Prob	Misid. Rate [/kg/d]	Gain	σ [cm^2]
CDMS II published	296	1	1.2×10^{-6}	1	7.2×10^{-4}	1	4.5×10^{-44}
CDMS II final	296	1	5.9×10^{-7} (analysis)	0.5	3.6×10^{-4}	2	2.3×10^{-44}
SuperCDMS Soudan	296	1	1.9×10^{-7} (mZIP)	0.17	1.2×10^{-4}	6	5×10^{-45}
SuperCDMS SNOLAB	90 (CDMS I rate)	0.3 internal shield, better stock	$< 1.7 \times 10^{-8}$ (iZIP)	< 0.014	1.5×10^{-6}	> 250	3×10^{-46}
GEODM DUSEL	90 (CDMS I rate)	0.3 internal shield, better stock	$< 1.2 \times 10^{-11}$? (iZIP)	$< 10^{-5}$?	1.1×10^{-9} ?	$> 3.3 \times 10^{5}$?	2×10^{-47}

Backgrounds and Background Rejection: Betas

- Surface events from low-energy beta decays
  - Significant reductions in raw rate/kg-d from reduced surface area/volume ratio and reduced radon daughter contamination
  - More significant improvements in background rejection via improved detector design (same as for photons; see later)

reduction of raw background rate via better shielding/reduced contamination

improvement in background rejection via better discrimination

Stage	Rate [/kg/d]	Relative Rate	Sgl. Scatter x Misid. Prob.	Relative Misid. Prob	Misid. Rate [/kg/d]	Gain	σ_{goal} [cm^2]
CDMS II published	3.4	1	1.0 x 10^{-4}	1	7.6 x 10^{-4}	1	4.5 x 10^{-44}
CDMS II final	3.4	1	5.3 x 10^{-5} (analysis)	0.5	3.8 x 10^{-4}	2	2.3 x 10^{-44}
SuperCDMS Soudan	0.83 x0.6 ^{210}Pb 2.5cm thickness	0.25	4.4 x 10^{-5} (mZIP)	0.42	7.9 x 10^{-5}	10	5 x 10^{-45}
SuperCDMS SNOLAB	0.60 3.5cm thickness	0.18	< 5 x 10^{-6} (iZIP)	< 0.05	< 3 x 10^{-6}	250	3 x 10^{-46}
GEODM DUSEL	0.41 5cm thickness	0.12	< 5 x 10^{-9} ? (iZIP)	< 5 x 10^{-5} ?	< 2 x 10^{-9} ?	> 3.7 x 10^{5} ?	2 x 10^{-47}

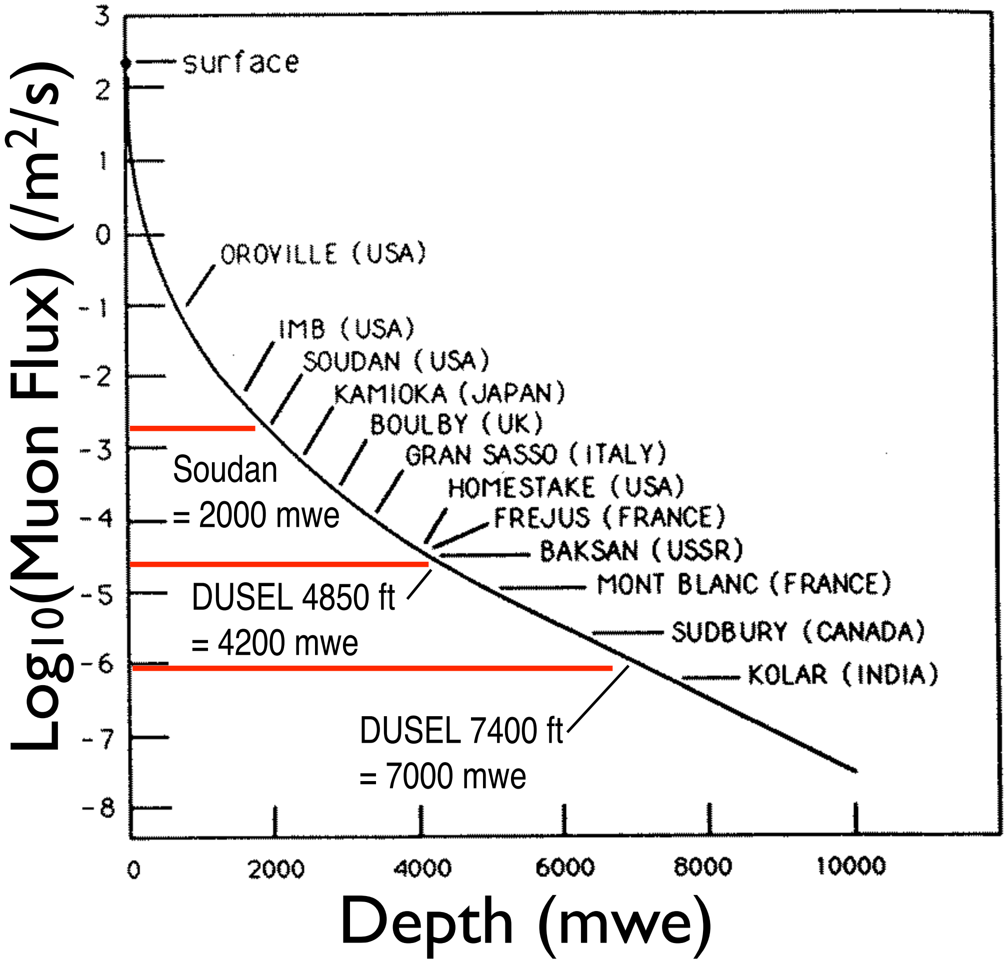
Backgrounds and Background Rejection: Neutrons

- Radiogenic neutrons: U/Th fission and (α,n)
  - Cryostat Cu:
    - 0.2 ppb U, 0.6 ppb Th currently, predicts 7.4 x 10^{-5} single n/kg/day
    - expected to be the limiting bgnd for SuperCDMS Soudan
    - Electroformed Cu should have 0.1 ppt U/Th
  - Pb in shield
    - 50 ppt *upper limit* on U/Th in existing shield
    - 1 ppt U/Th (Heusser *upper limit*) yields 6x10^{-6} single n/kg/day for SuperCDMS Soudan; ok for SNOLAB, need to improve upper limit by x15 for GEODM
  - Polyethylene:
    - 0.2 ppb U, 0.2 ppb Th upper limits on existing material yield 1.6 x 10^{-5} single n/kg/day
    - Need improved poly (x3 and x45) or replace with water

Stage	Rate [/kg/d]	Relative Rate	Gain	σ [cm^2]
CDMS II published	1.2 x 10^{-4}	1	1	4.5 x 10^{-44}
CDMS II final	1.2 x 10^{-4}	1	1	2.3 x 10^{-44}
SuperCDMS Soudan	1.2 x 10^{-4}	1	1	5 x 10^{-45}
SuperCDMS SNOLAB	6.0 x 10^{-6}	0.05	20	3 x 10^{-46}
GEODM DUSEL	4.0 x 10^{-7}	0.003	300	2 x 10^{-47}

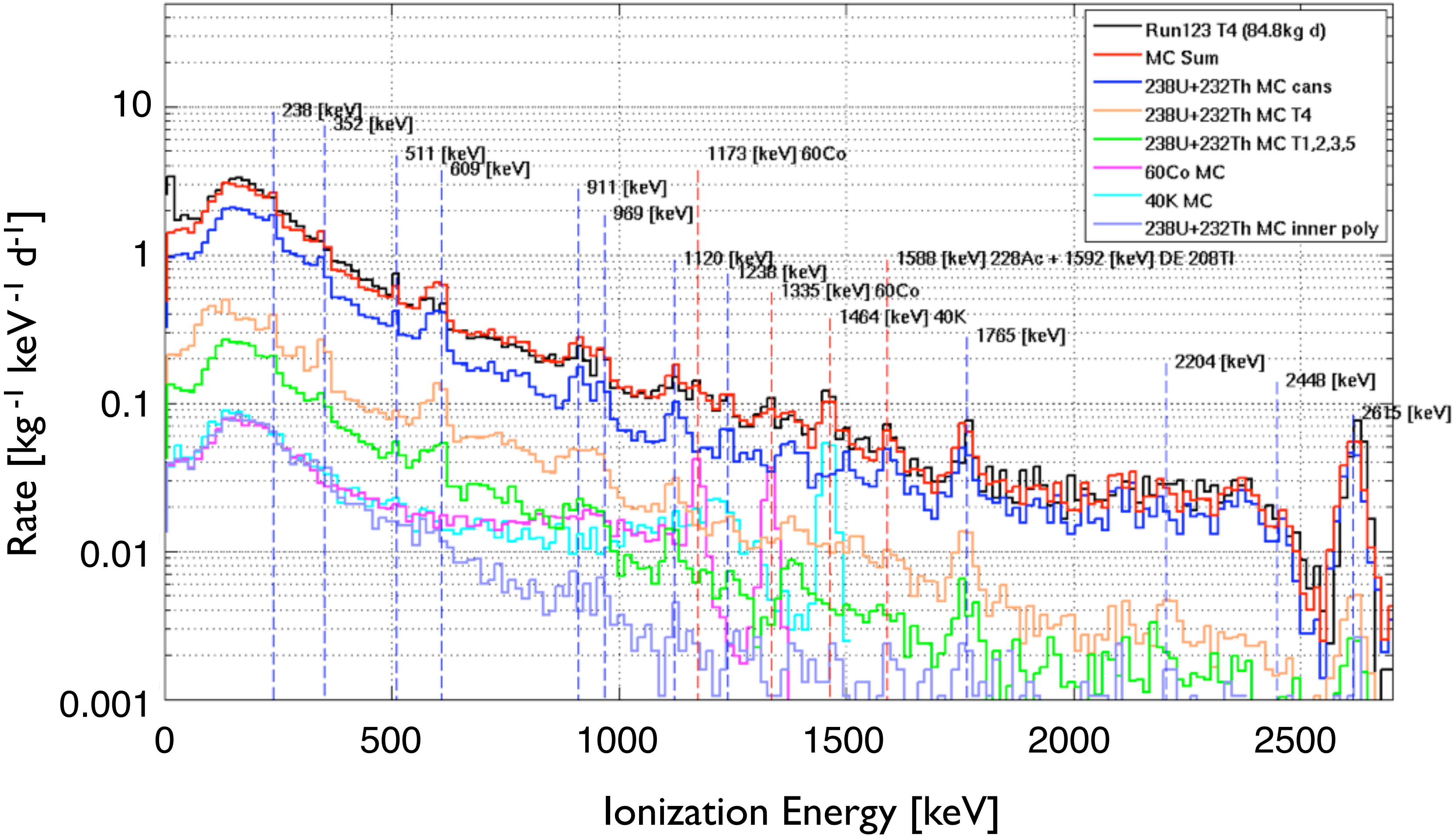
Backgrounds and Background Rejection: Neutrons

- Cosmogenic neutrons:
  - cosmic-ray muon spallation of nuclei in rock walls
  - muon rate is >1000x lower than Soudan at DUSEL 7400 ft level
  - showering greatly aids in vetoing
  - 7400 ft level vs. 4850 ft level + active shield: cosmogenic activity could still be a worry if intrinsic EM background rejection is limited (e.g. LXe)



Reducing Backgrounds: Photons and Radiogenic Neutrons

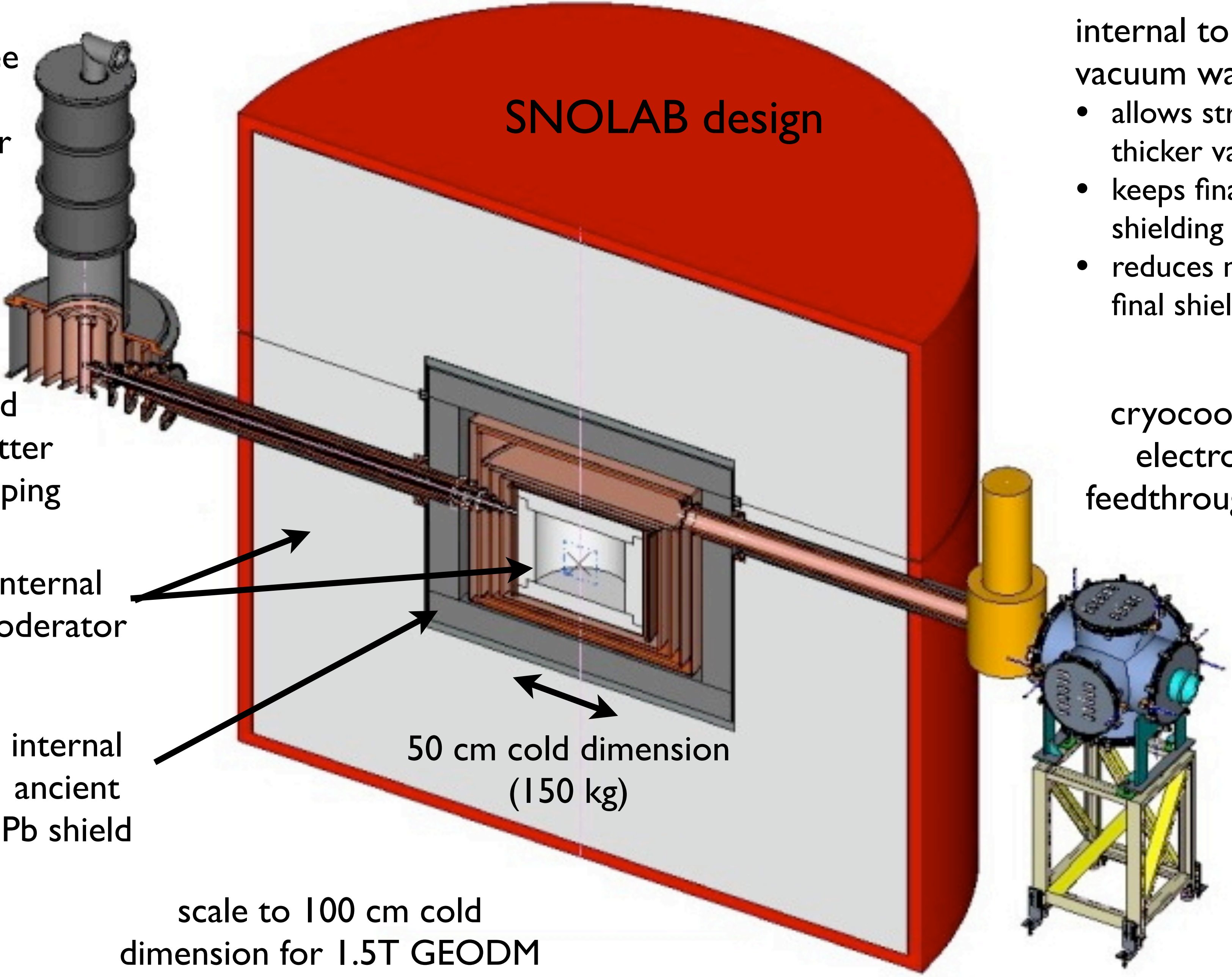
- Fit spectrum for ^{238}U/^{232}Th/^{40}K/etc. contributions from various components
  - CDMS II = gamma screener. MC predicts spectrum for contaminants in various locations
  - Rate dominated by U/Th from cryostat/cold hardware Cu
  - x10 lower contributions from ^{40}K, ^{60}Co in Cu, U/Th in polyethylene
- Contamination levels typical for non-electroformed Cu



Reducing Backgrounds: Photons and Radiogenic Neutrons

- SNOLAB: need 70% reduction in photons, x20 in neutrons
  - cut photons using internal ancient Pb (done in CDMS I)
  - switch to electroformed Cu to reduce photons further, kills neutron contribution (x1000 better)
  - Pb: ok if U/Th in Pb is at Heusser upper limits (1 ppt)
  - need x3 on moderator: mildly cleaner polyethylene
- GEODM: need x15 more in neutrons
  - electroformed Cu should be ok
  - need to tighten upper limits on U/Th in Pb by x15
  - moderator: Need to work on this. No known vendor for lower U/Th poly (need to better understand how it is incorporated). Water is a reasonable alternative.

Reducing Backgrounds: SNOLAB/GEODM Cryostat/Shield



SNOLAB design

cryogen-free
dilution
refrigerator

expanded
tails for better
access/pumping

internal
moderator

internal
ancient
Pb shield

50 cm cold dimension
(150 kg)

scale to 100 cm cold
dimension for 1.5T GEODM

inner shielding layer
internal to cryostat
vacuum wall

- allows stronger/ thicker vacuum wall
- keeps final layer of shielding clean
- reduces mass of final shield (esp. Pb)

cryocooler on
electronics
feedthrough stem

Improving Background Rejection

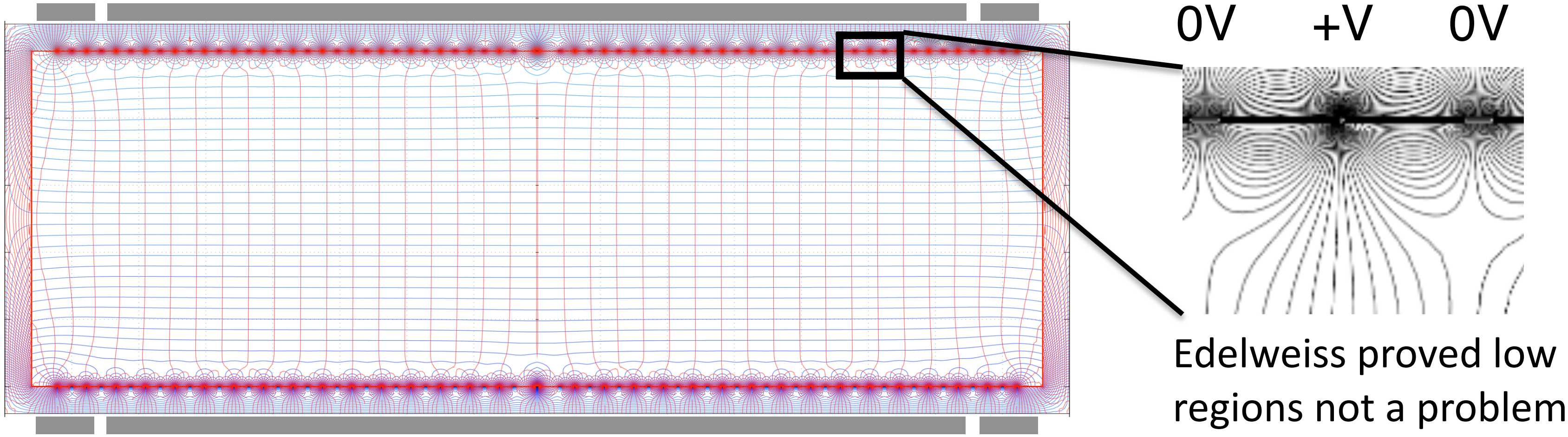
- CDMS II History:
  - ~0.5 expected misid'd bgnd in each analysis to date over x10 increase in exposure by improved analysis techniques with existing detectors

Year	Exposure (raw Ge)	Limit alone	Limit incl. previous
2004	53 kg-d	4.0×10^{-43} cm^2	4.0×10^{-43} cm^2
2005	112 kg-d	2.5×10^{-43} cm^2	1.6×10^{-43} cm^2
2008	398 kg-d	6.6×10^{-44} cm^2	4.6×10^{-44} cm^2
2009	~1100 kg-d	~2.6×10^{-44} cm^2	~2.3×10^{-44} cm^2

- SuperCDMS Soudan:
  - Only need to obtain surface event rates (per unit area) comparable to best CDMS II detectors and rejection comparable to CDMS II final analysis (x2 better than published)
  - ^{210}Po alpha rate already checked → ^{210}Pb ok!
    Explicit demonstration of surface event rate/rejection with SuperTower 1 in coming months.

Improving Background Rejection

- Interdigitated ZIP (iZIP) design meets needs for SuperCDMS SNOLAB and GEODM

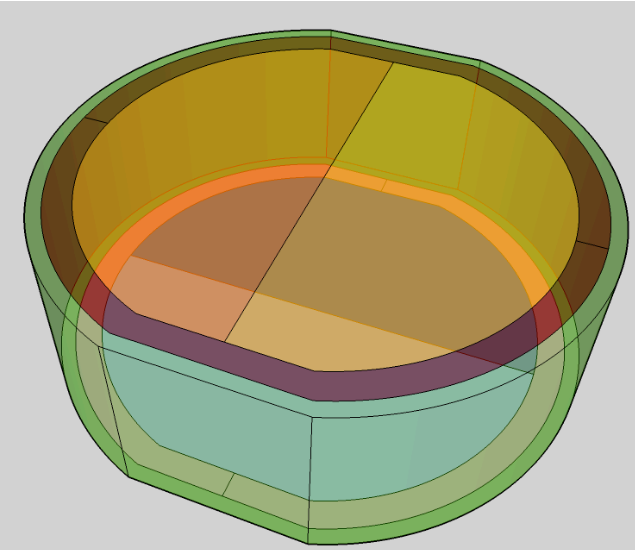


negative
version
on other face

Edelweiss proved low field regions not a problem

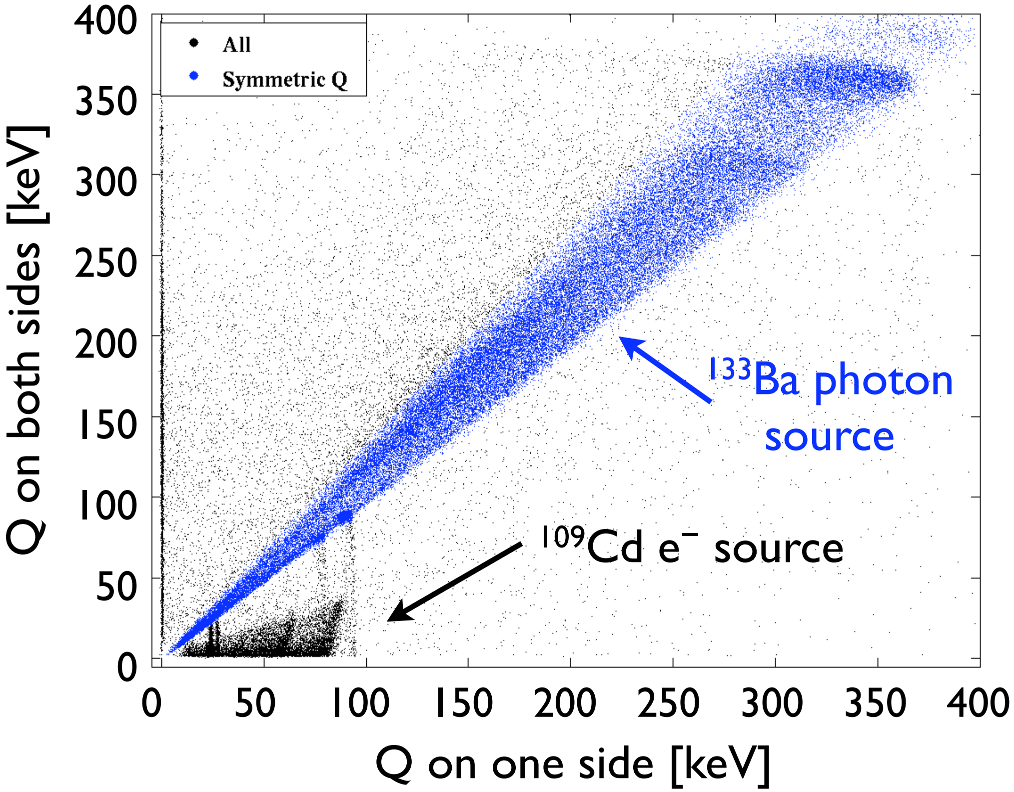
M. Pyle

- Interleaved ionization electrodes cause ionization to partition differently for surface and bulk events
- High field near surface increases ionization yield for surface events
- Top/bottom phonon sensors (ground rails) provide simpler, more direct z information



Improving Background Rejection

- Interdigitated ZIP (iZIP) design appears to meet needs of SuperCDMS SNOLAB and GEODM
  - Surface events share charge differently than bulk events: < 10^{-3} misid
  - High field at surfaces increases ionization yield: 0.2 misid → < 3 x 10^{-4} misid
  - Phonon partition and timing z position: < 10^{-3} misid



M. Pyle, B. Serfass

- All measurements limited by neutron background in surface test facilities
- Ionization yield and Q/P asymmetry likely uncorrelated; if true, then overall misid 10^{-4} → < 3 x 10^{-7}, far better than needed for GEODM

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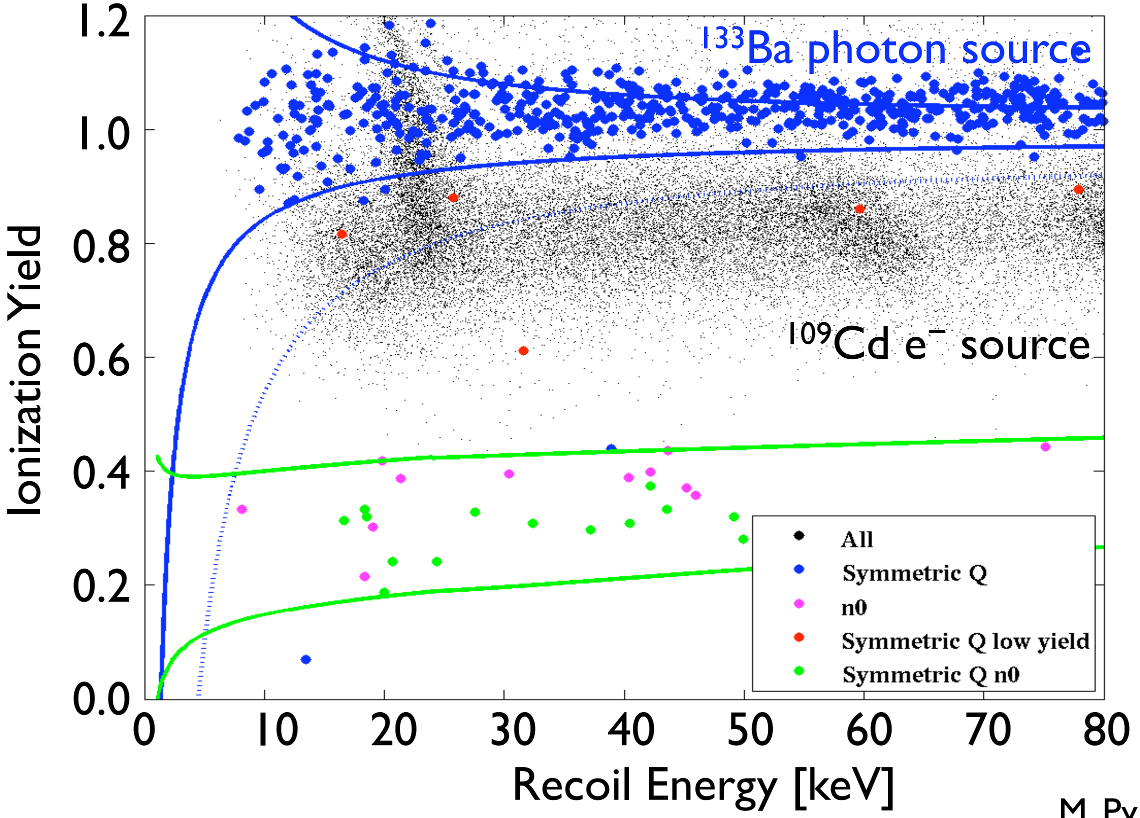

M. Pyle, B. Serfass

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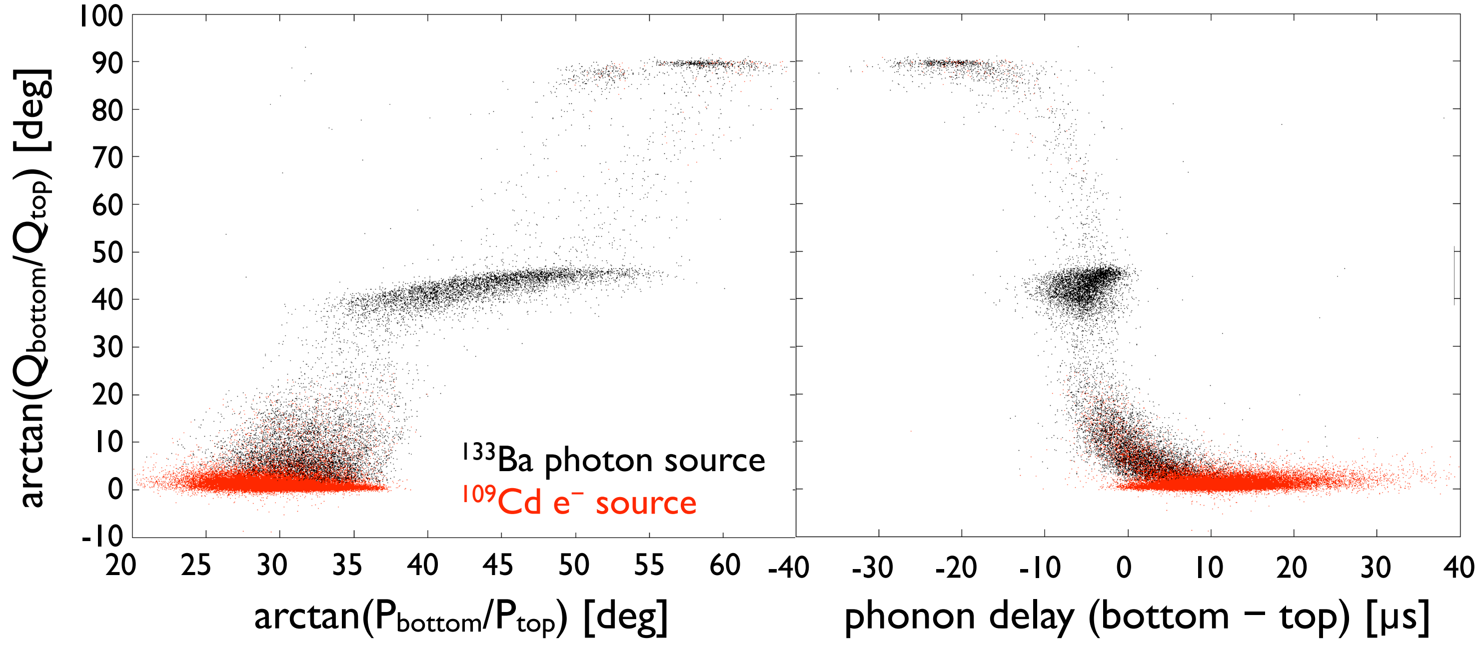

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Reducing Cost/Time: Larger Substrates

- Larger substrates provide gains in bgnds and in cost/time per kg
- Step 1: 10-cm HPGe substrates (Ortec)
- Step 2: Dislocation-free Ge
  - deep (Ev + 0.080 eV) V_2H impurity ruins 77K HPGe γ spectrometers; inhibited via dislocations at 10^{2-4} cm^{-3} created by thermal gradients during crystal pulling
  - impurity no problem for CDMS: impurities are neutralized
  - dislocation-free xtals available up to 30 cm diameter!

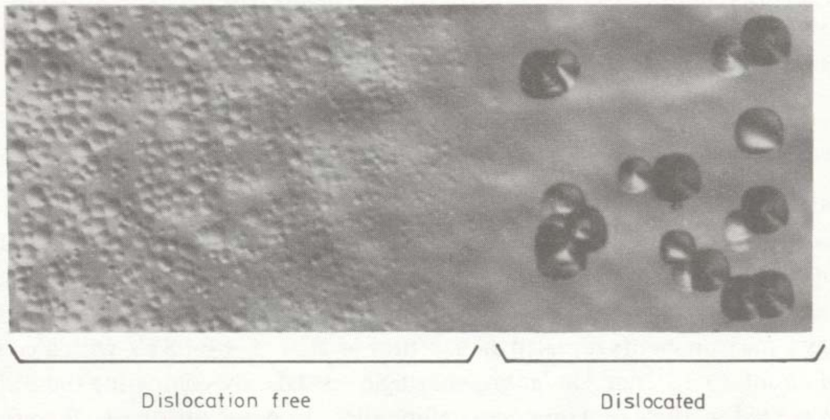

Figure 2. Photograph of a partially dislocated (100) surface of a hydrogen-grown Ge crystal. The large etch pits with four-fold symmetry in the right half of the picture are due to dislocations. The hemispherical pits in the left half of the picture are attributed to vacancy and hydrogen complexes.

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Divacancy–hydrogen complexes in dislocation-free high-purity germanium †

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‡ Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720, USA
§ Max-Planck-Institut für Metallforschung, Stuttgart, Germany

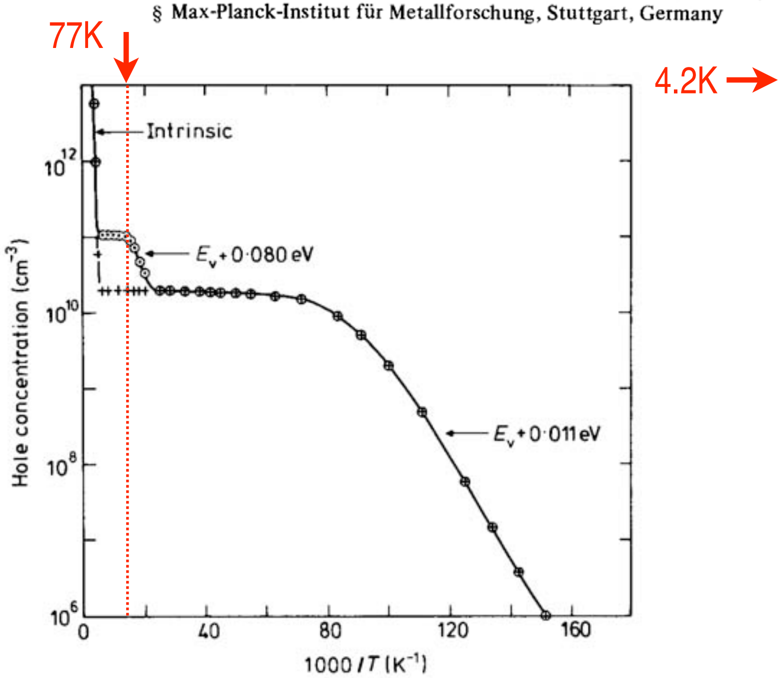
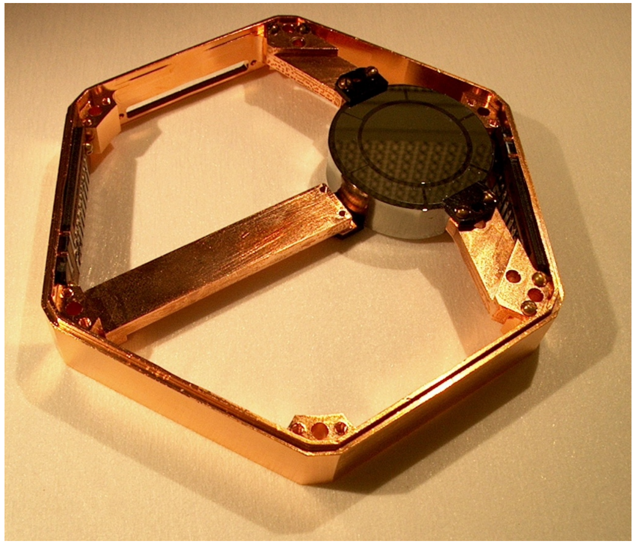
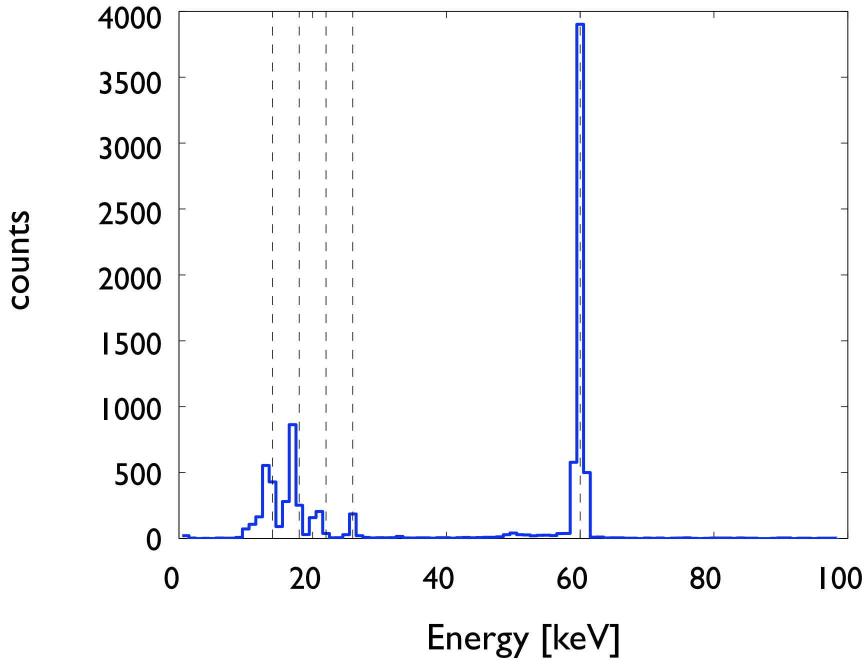


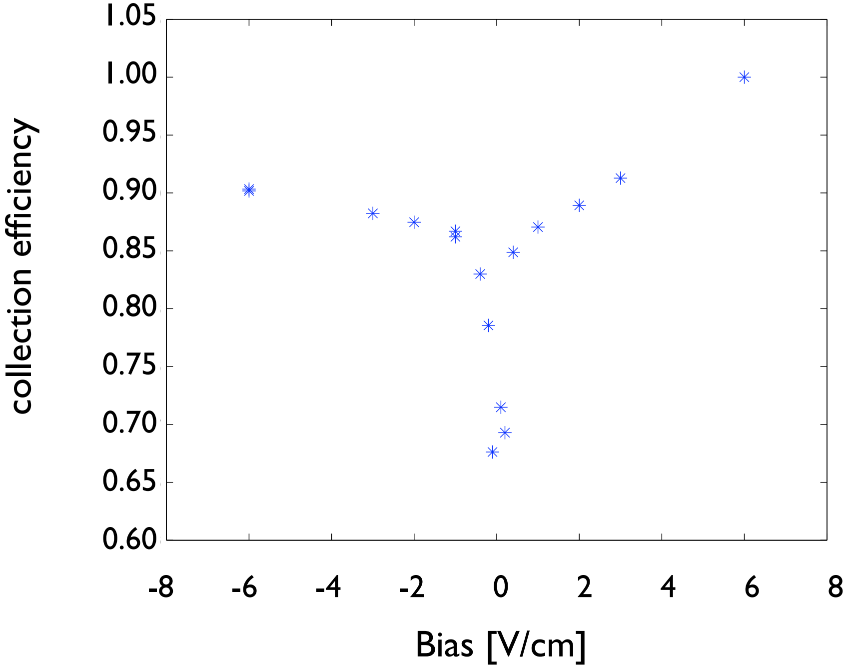
Figure 1. Hole concentration against reciprocal temperature $1/T$ of a dislocated and an undislocated Ge sample cut from the same crystal slice. The net impurity concentration of shallow acceptors and donors is equal for both samples. The $E_V + 0{\cdot}08$ eV acceptor only appears in the dislocation-free piece; its concentration depends on the annealing temperature. ⊙ dislocation free; + dislocated.

Reducing Cost/Time: Larger Substrates

- Proof-of-principle from Haller sample of dislocation-free Ge (3 cm x 1 cm)
  - Good collection at 1 V/cm (reasonable field)
- Working with Umicore and Photonic Sense to demonstrate 15-cm fab at necessary purity/compensation levels
  - DUSEL R&D grant, DUSEL S4 grant
  - Germanium workshop in Berkeley this fall

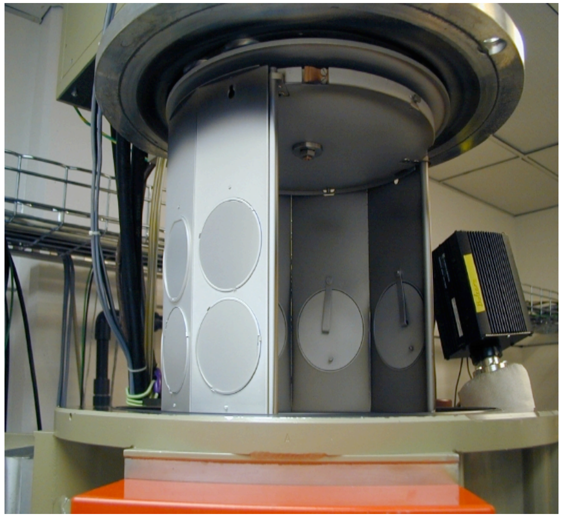


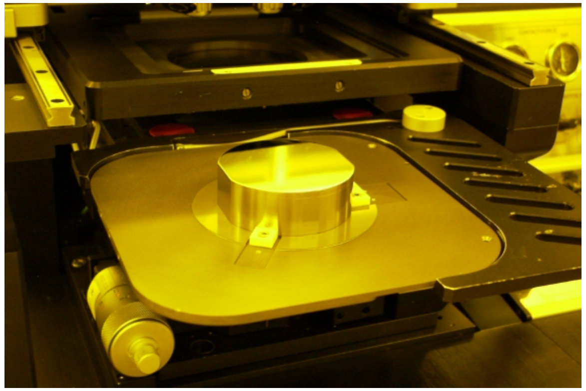


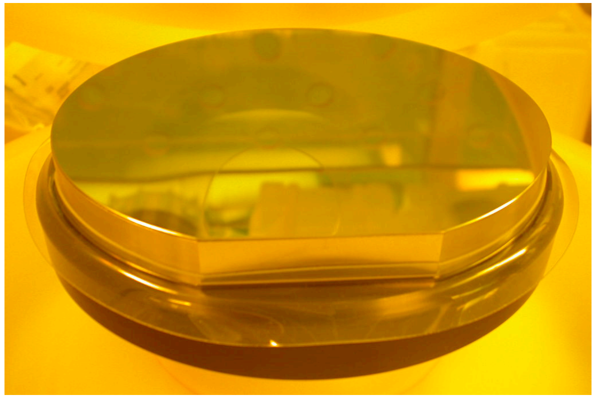


Reducing Cost/Time: Demonstrated Fab Improvements

- Film deposition control
  - CDMS II used shared sputtering machine;
    → poor tungsten Tc control, much effort to monitor
  - Have taken full possession of sputtering machine and installed fresh tungsten target
  - Machine already upgraded to 2.5 cm thickness and producing them regularly
- Photolithographic mask aligner/exposer
  - Former stepper/aligner (Karl Suss Ultratech): difficult to use and defect-prone
  - New EV-620 leaves smiles on the faces of users (literally). Has been upgraded to accept 15-cm diameter x 5-cm thickness.
  - New machine provides for full-field masks (more flexibility in sensor design)
- Demonstrated photoresist spinning on Ti blanks
- Already increased fab rate, reduced fab cost
- (DUSEL R&D grant, KIPAC, DUSEL S4 grant)

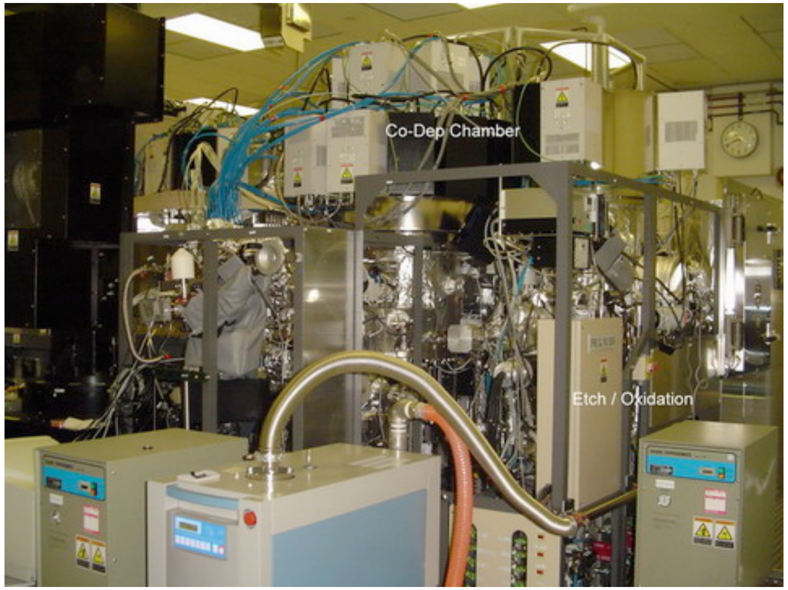


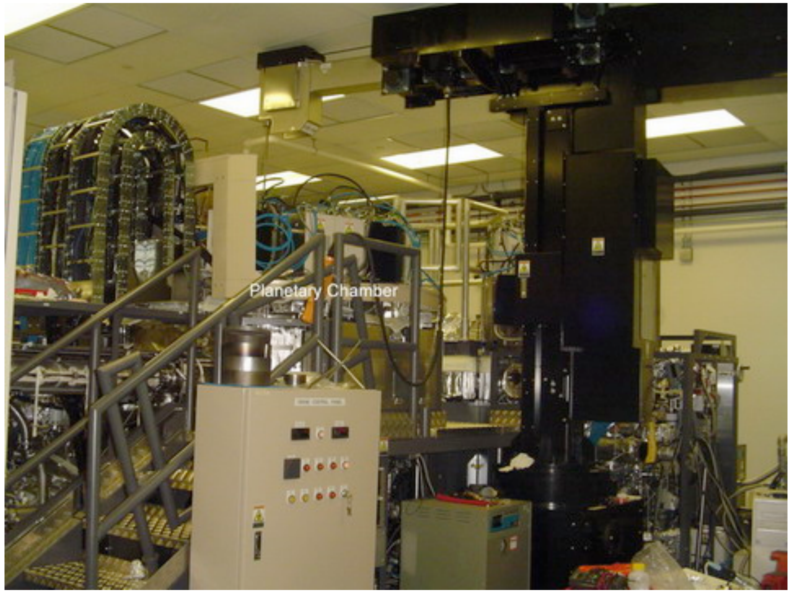




Reducing Cost/Time: Proposed Fab Improvements

- SuperCDMS SNOLAB
  - 10-cm substrates can be processed in existing Stanford facility
- GEODM
  - Develop fab line at TAMU (Mahapatra):
    - new automated sputter cluster donated by Seagate; available for dedicated use
    - clean room donated by Dallas Semiconductor
    - Already handles 15-cm diameter, needs to be upgraded to 5-cm thickness ($50k)
    - Purchase automated photoresist coater/baker ($200k)
      - 40% of fab time goes into PR coat/bake!
  - New SLAC group (do Couto e Silva)
    - managed Fermi GST LAT fabrication
    - looking to establish fab line at SLAC, possibly in time for SNOLAB
- Above will allow almost full automation and 24/7 fabrication: fab cost/time should not be a limiting factor





Reducing Cost/Time: Test Improvements

- Fab improvements → test improvements
  - CDMS II:
    - detectors required 3 cryogenic tests to obtain full functionality (surgery to repair fab errors, T_c test and implantation to tune)
    - once detector functional, success rate for getting into experiment was 80%
  - SuperCDMS:
    - tungsten film T_c under good control, no surgery required: 1 cryogenic test required to obtain fully functional detector
    - success rate for completed substrates 80% so far, should improve
- Test speedup/automation
  - Much testing for CDMS II was fully manual
  - Will develop cryogen-free automated test setup to measure T_c, demonstrate DC functionality
  - 3 new test facilities now online or coming online soon (UF, UMN, Queen's), two are cryogen-free, but losing CWRU
  - SuperTower 1 already shows substantial improvement over CDMS II

Reducing Cost/Time: Doing the Numbers

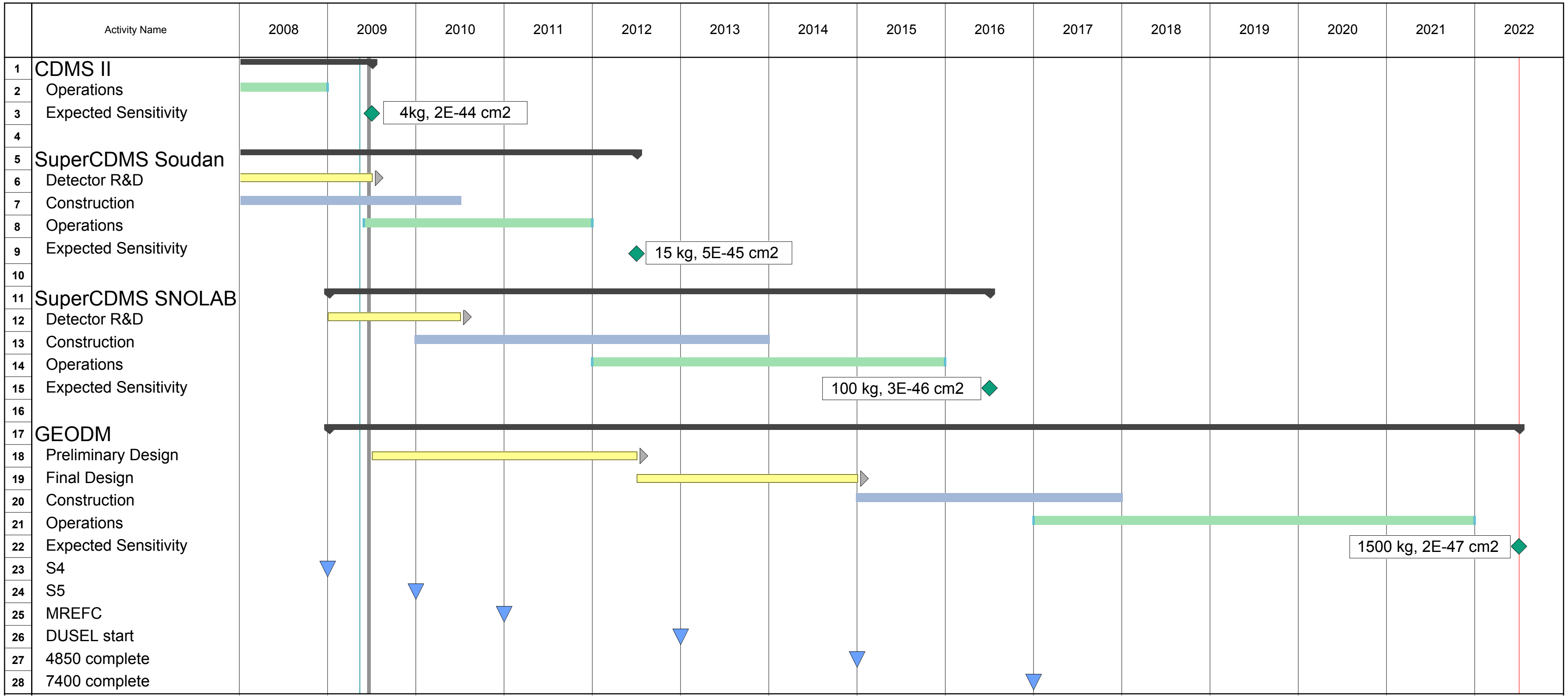
- How do you cost things?
  - “development” costing
    - add up costs under the “Fabrication/Test” work breakdown structure category; divide by number of detectors
  - “production” costing
    - add up at the actual time spent and related expenses
- Super Tower 1 + 2 (10 Ge detectors)
  - “development”:
    - project has run almost 2 yrs and almost have 10 detectors ready
      (5 done, 5 fab’d and to be tested in next 2 mo)
      → 0.5 detectors/mo, $500k/detector
  - “production”:
    - were in development mode through 10/2008;
      look at 11/2008-3/2009, once fab process has been set
      → 1.25 detectors/mo, $160k/detector
    - 3/4 of time is test: need to speed up/automate testing
  - In “production” costing, we have met SuperCDMS Soudan goal

Reducing Cost/Time: Doing the Numbers

- Costs for fab *and* test; product = detector ready for installation in experiment
  Has driven experiment cost in past.

	CDMS II	**SuperCDMS Soudan**	**SuperCDMS SNOLAB**	**GEODM**
Cost basis	actual	approved	to be proposed	
total mass	4 kg	16 kg	105 kg	1500 kg
# detectors, mass	16 x 0.25 kg (+ 14 x 100g Si)	25 x 0.64 kg	70 x 1.5 kg	300 x 5.1 kg
cost/detector	$200K-$300K	$225k	$225k	$120k
rate [det/mo]	0.5-0.75/mo	1/mo	2/mo	8/mo
cost/kg	$800k-1200k	$350k	$150k	$24k
rate [kg/mo]	0.1-0.2 kg/mo	0.64 kg/mo	3 kg/mo	40 kg/mo
total detector cost	$4.8M (+ $4.2M)	$5.6M	$16M	$36M
total detector time	2.7 yrs (+ 2.3 yrs)	2 yrs	3 yr	3 yrs

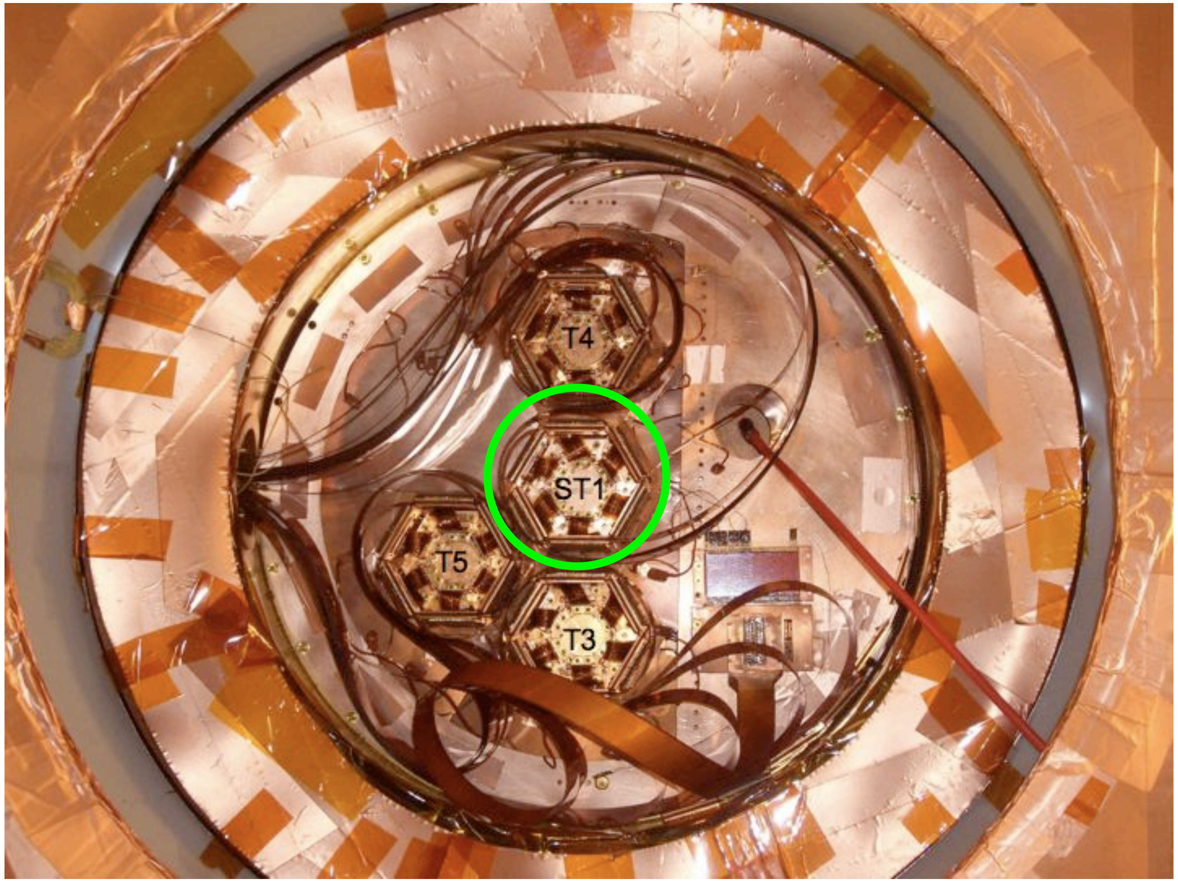
Status/Schedule

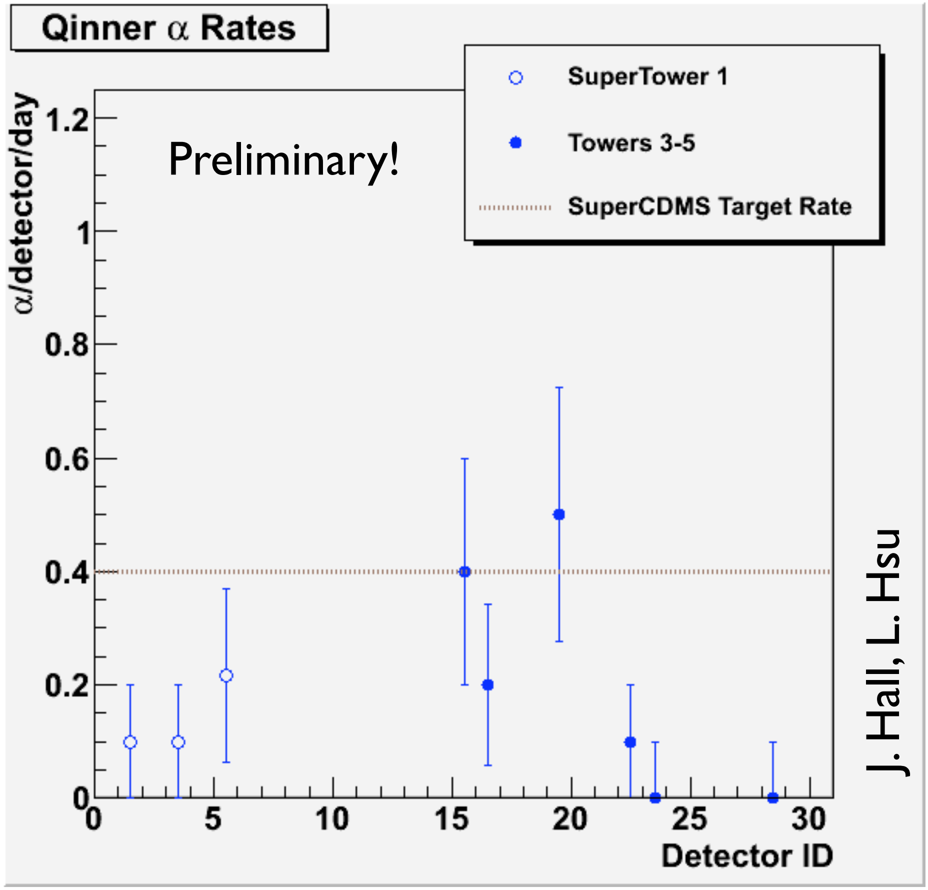


- CDMS II:
  - data taking complete
  - final analysis proceeding, out this fall
- SuperCDMS Soudan:
  - First 3.2 kg of detectors installed in Soudan (along with existing 2.4 kg), second 3.2 kg of detectors fab’d and awaiting surface testing
  - Approved in Aug 2008 to fab remaining 9.6 kg of detectors and run for 2 yrs

SuperTower 1 Running at Soudan!

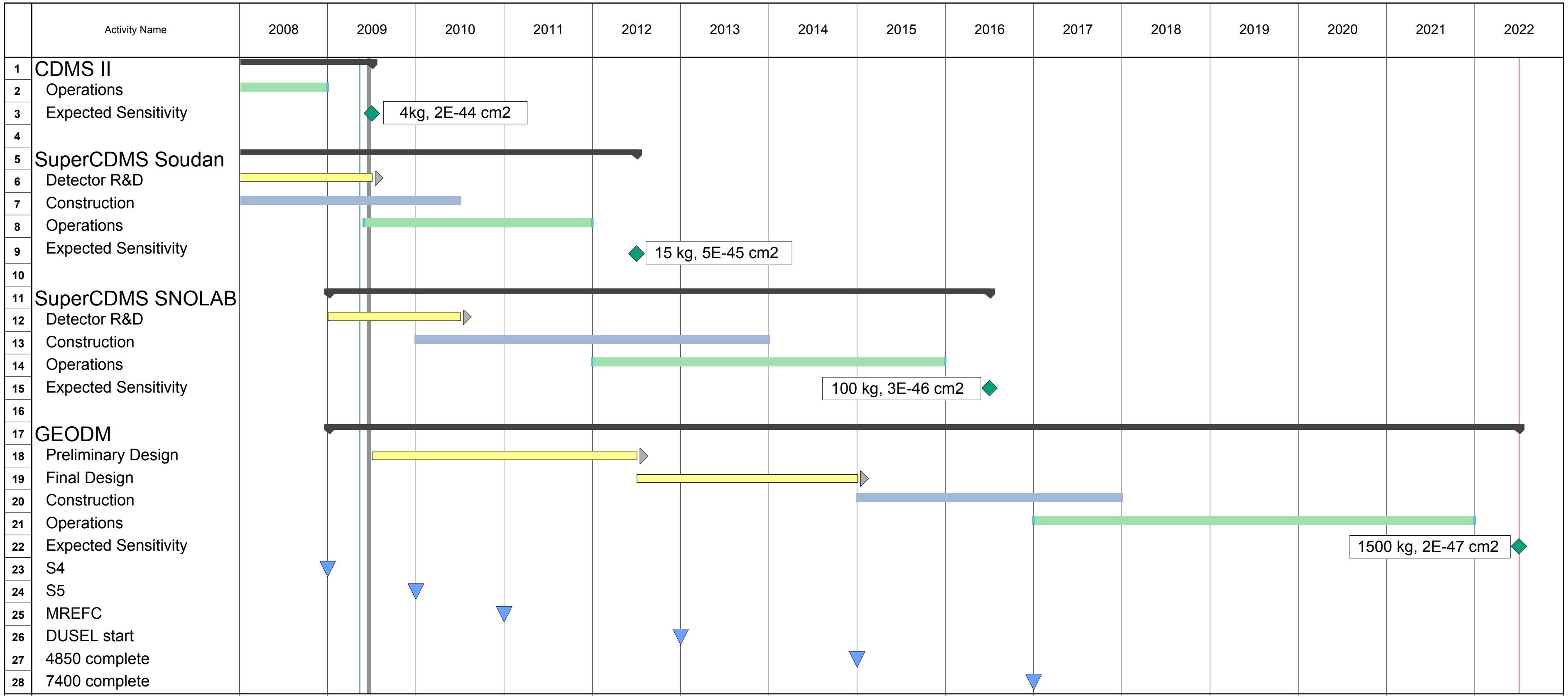
- ST1 installed April 16, 2009, cold June 4, and in stable running by Aug 1
- Best 3/5 of CDMS II also remains in place: total 4 kg → 5.6 kg
- ^{210}Po α rate verified; surface-event rates and rejection need more data
- will run ST1 alone until ST2-5 ready





J. Hall, L. Hsu

Status/Schedule



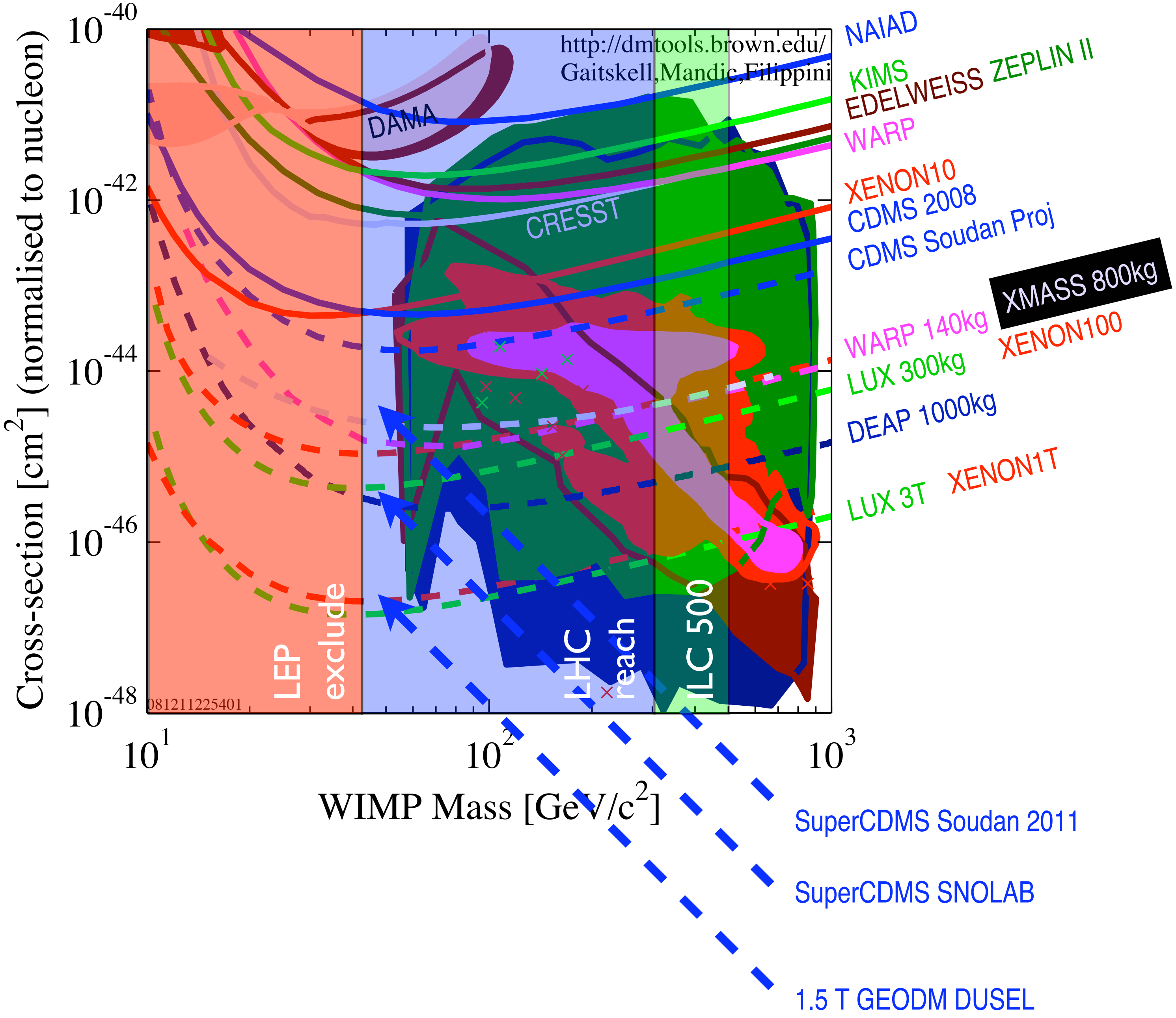
- SuperCDMS SNOLAB:
  - R&D funding likely in FY10, proposal to be submitted in FY10 for FY11 start
  - Cryostat/shield and electronics design proceeding at FNAL under base funding; critical to get release of funds to order long-lead-time dilution refrigerator ASAP
  - SNOLAB is enthusiastic, space has been set aside, initial test setup in FY10
  - Overlap with DUSEL provides prototyping, robustness against DUSEL delays: *SNOLAB reach not limited by site* (or, hopefully, by cryostat and shield)

Status/Schedule

- DUSEL GEODM
  - Conceptual design and initial cost estimate ($50M construction) in hand
  - DUSEL S4 (engineering study phase) proposal successful!
    $2.1M proposed over 3 yrs, $1.3M funded
    - Goal: arrive at "preliminary design" of experiment by end of funding in 2012, with input to DUSEL preliminary design in late 2010 (DUSEL PDR: Dec 2010).
    - Pursuing parallel DOE funding
      - FNAL: situation looks tight right now; continued base funding ok, large increment unlikely
      - SLAC: enthusiasm from Particle Physics/Astro Director
        Eduardo do Couto e Silva (Fermi GLAST) has just joined with view toward large detector fab and simulations, $500k/yr LDRD just submitted
      - LBNL: enthusiasm from Siegrist, funding situation looks difficult (no base engineering budget)
      - University: Have asked whether we can submit a "companion proposal" to S4, no response yet, but hopefully enthusiasm from the labs will encourage Kovar.
      - PASAG report will hopefully help
  - Overlap with SNOLAB provides prototyping, robustness against DUSEL delays

Exciting Times!

- Remarkable progress
  - 2 orders of mag in ~10 yrs
  - Predictions for larger gains in next decade
- LHC turn-on soon!
  - perhaps a prediction based on detecting SUSY; perhaps a confirmation of a DD signal



Conclusions

- CDMS II reaching successful completion
- SuperCDMS Soudan ramping up
  - ST1 installed and ^{210}Po verified, ST2 to be tested
  - approved for ST3/4/5 + science running
  - reach: 5 x 10^{-45} cm^2
- SuperCDMS SNOLAB to be proposed soon
  - 105 kg, 3 x 10^{-46} cm^2
  - new SLAC involvement
- GEODM
  - conceptual design in place
  - preliminary design beginning