Cryogenic Dark Matter Search (CDMS)

The Frontier of WIMP Direct Detection

Dark matter physics - A brief reminder

Overview of the experiment

Science results produced thus far

Current status at Soudan

Prospects at Soudan

The Future - SuperCDMS (Blas Cabrera)

Dan Bauer - CDMS Project Manager

CDMS Collaboration at Soudan

DOE Laboratory
Fermilab
LBNL

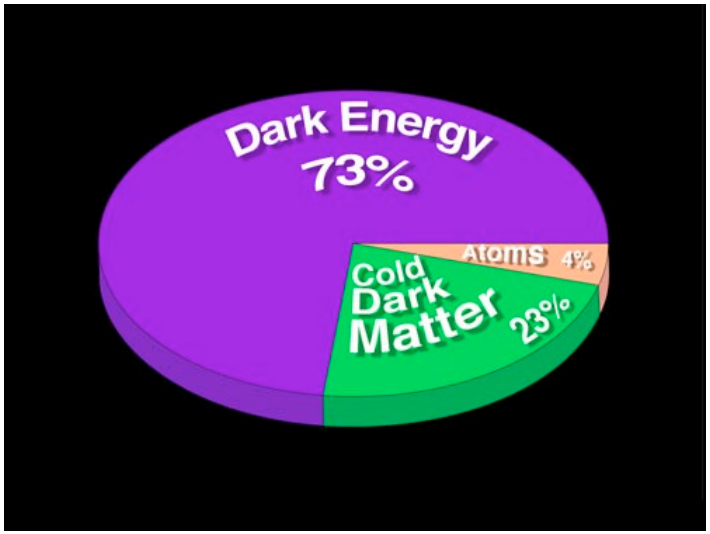
DOE University
Brown
CalTech
Florida
Minnesota
MIT
Stanford
UC Santa Barbara

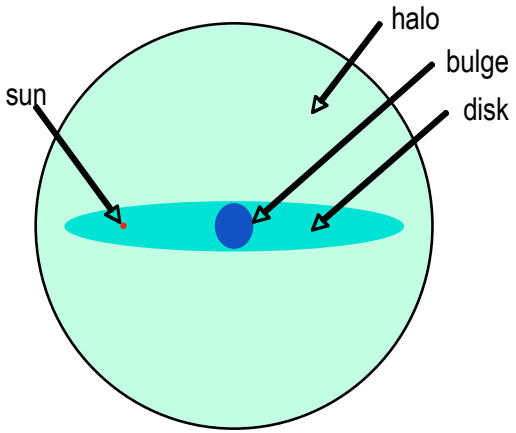
NSF
Case Western Reserve
Colorado (Denver)
Santa Clara
UC Berkeley

Canada
Queens

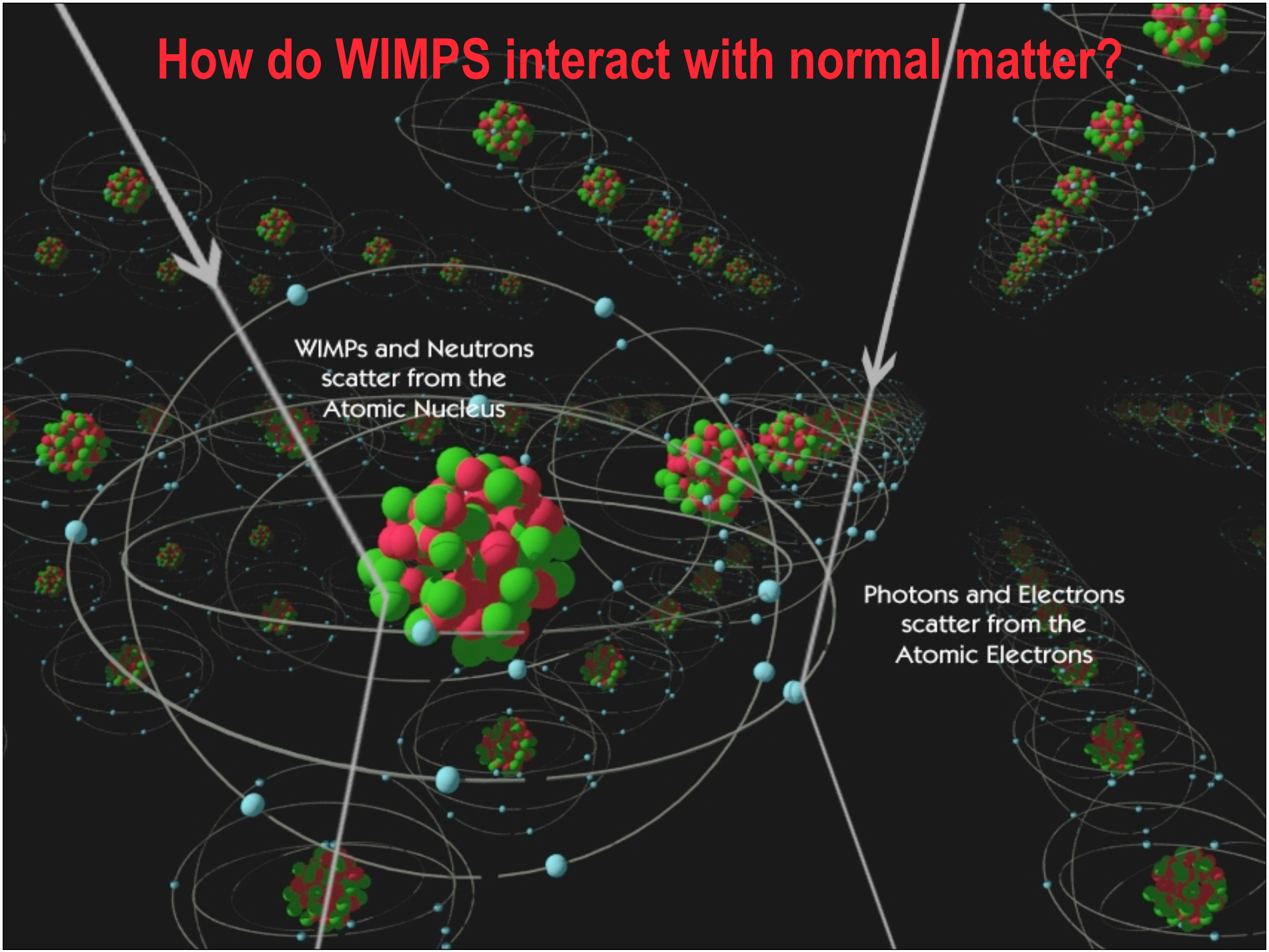
The Physics

- Cold dark matter makes up nearly 1/4 of the mass/energy and most of the matter in the universe!
- Particle candidates for CDM
  - WIMPs (GeV-TeV masses)
    - SUSY neutralinos
    - Kaluza-Klein excitations
  - Axions (10^{-3} -> 10^{-6} eV masses)
- Dark matter responsible for galaxy formation
  - We are moving through a dark matter halo
- How can we directly detect if these are WIMPS?





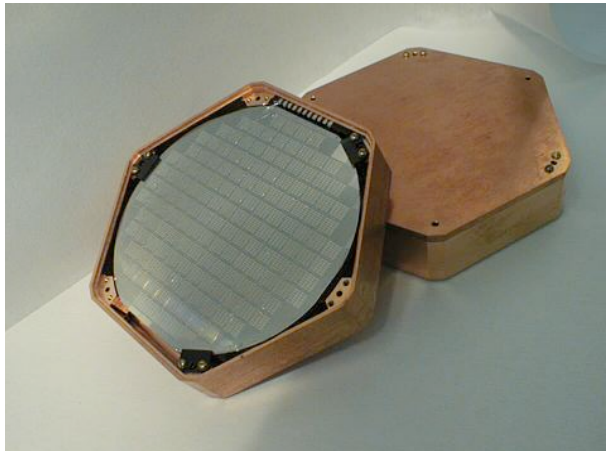
How do WIMPS interact with normal matter?



How to distinguish nuclear and electron recoils

Detectors with readout of both charge and phonon signals

- Charge/phonon AND phonon timing different for nuclear and electron recoils; event by event discrimination!
- Measured background rejection still improving!
  99.9998% for γ's, 99.79% for β's
- Clean nuclear recoil selection with ~ 50% efficiency
  Can tune between signal efficiency and background rejection



Tower of 6 ZIPs

Tower 1

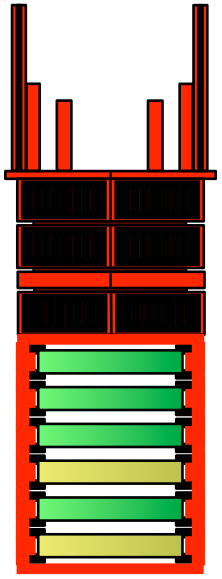
4 Ge

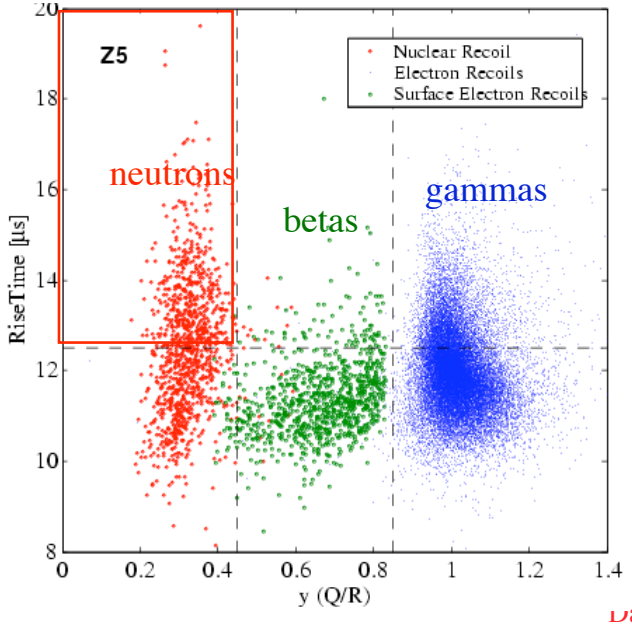
2 Si

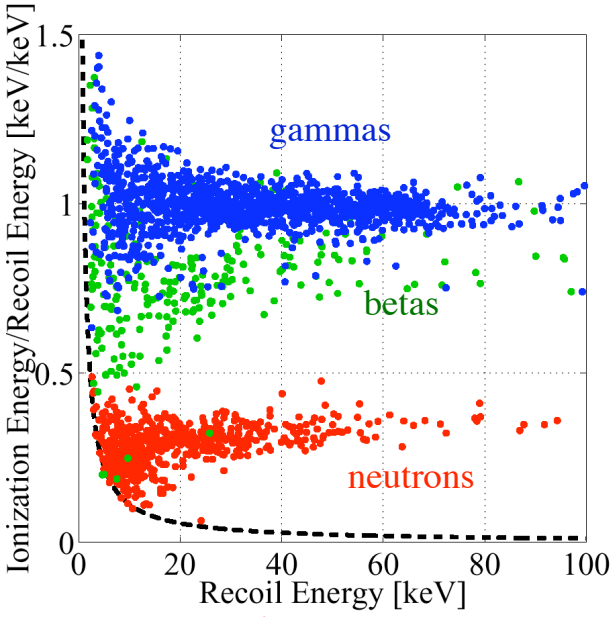
Tower 2

2 Ge

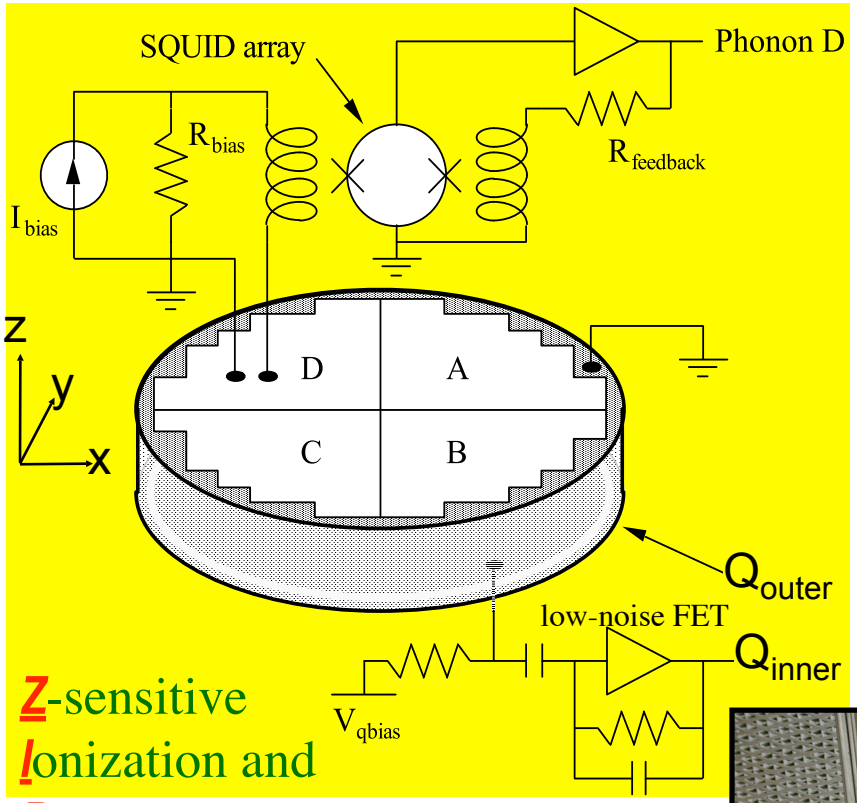
4 Si







Really Cool Detectors: ZIPs



Z-sensitive
Ionization and
Phonon-mediated

Measure ionization in low-field (~volts/cm) with segmented contacts to allow rejection of events near outer edge

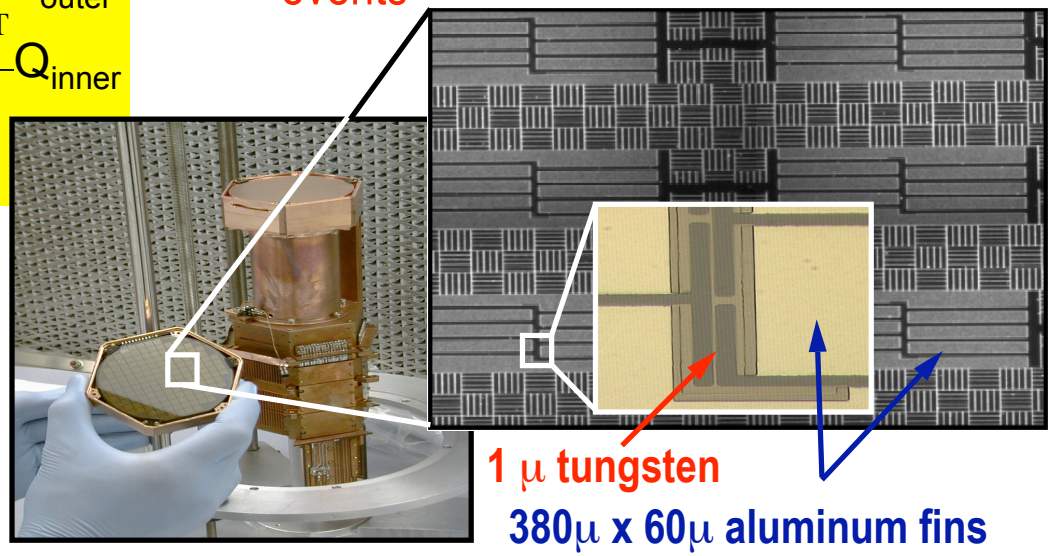
250 g Ge or 100 g Si crystal

1 cm thick x 7.5 cm diameter

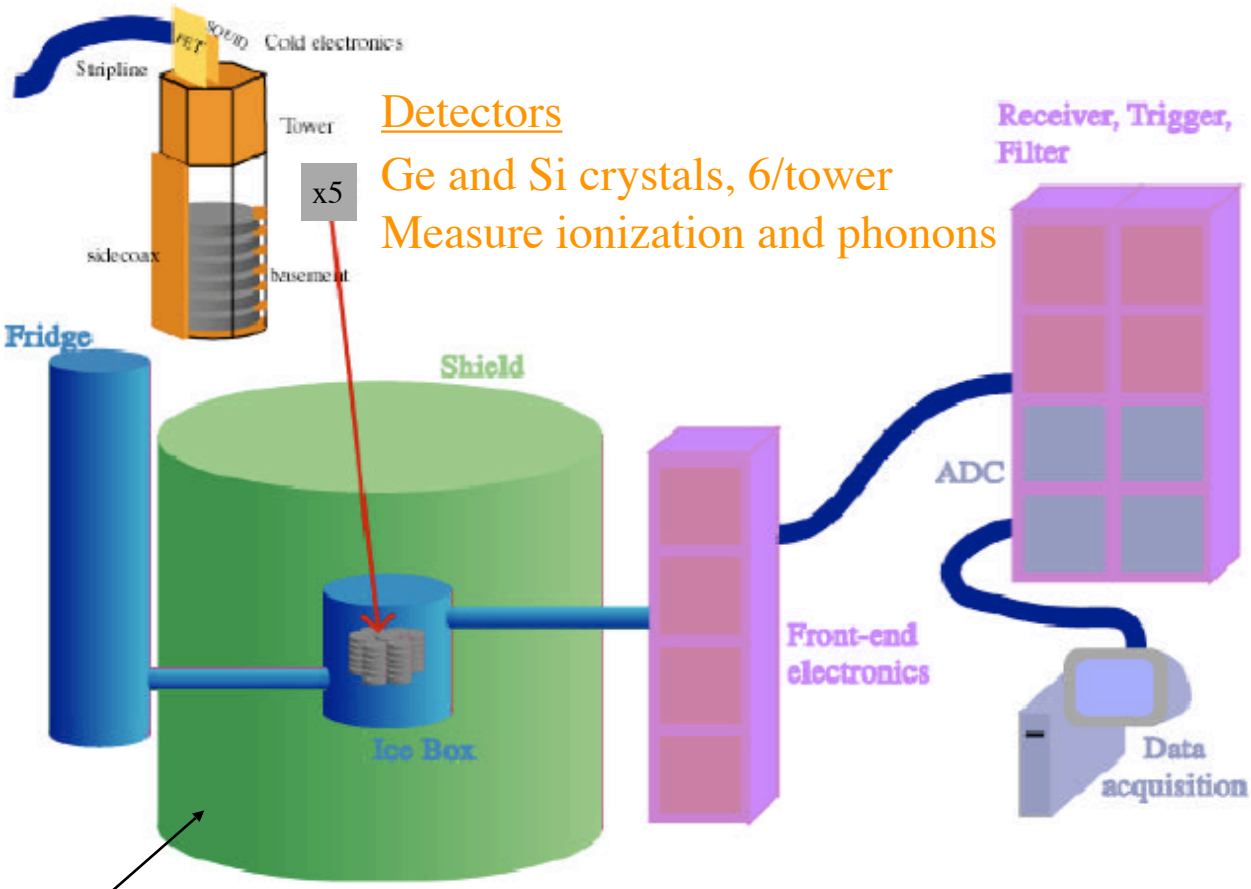
Photolithographic patterning

Collect athermal phonons:

- Crystal lattice vibrations
- Speed of sound in crystal ~ 1 cm/ms results in measurable delays between the pulses of the 4 phonon channels => distinguish surface from bulk events



Layout of the experiment



Detectors

Ge and Si crystals, 6/tower

Measure ionization and phonons

Cryogenics

Maintain detectors at 50 mK

Electronics /DAQ

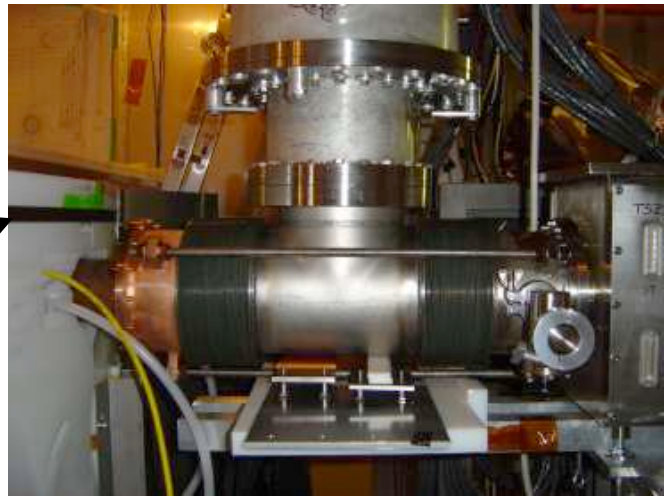
Record signals from detectors and veto; form trigger

Shielding

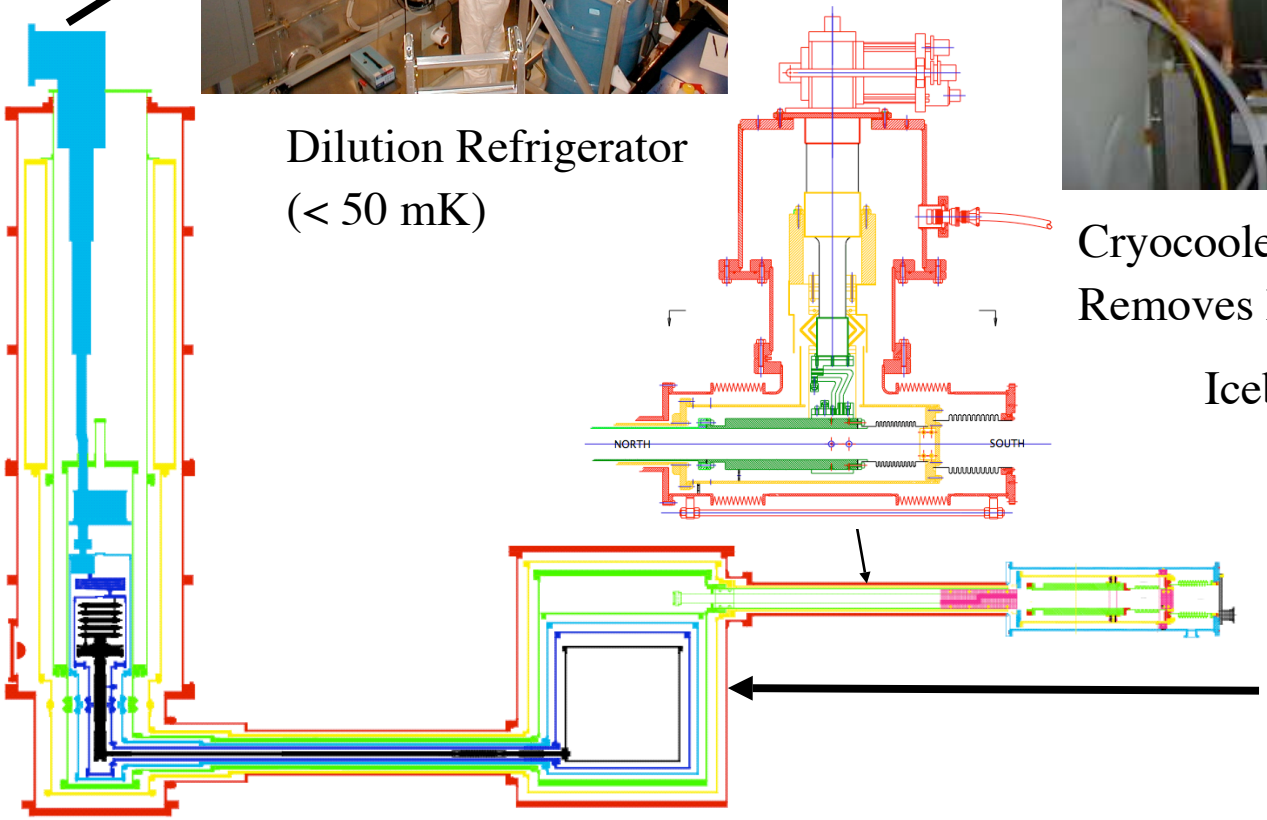
Layered shielding (Cu, Pb, polyethylene) reduces radioactive backgrounds and active scintillator veto is >99.9% efficient against cosmic rays.

Cryogenics: How to get really cold!

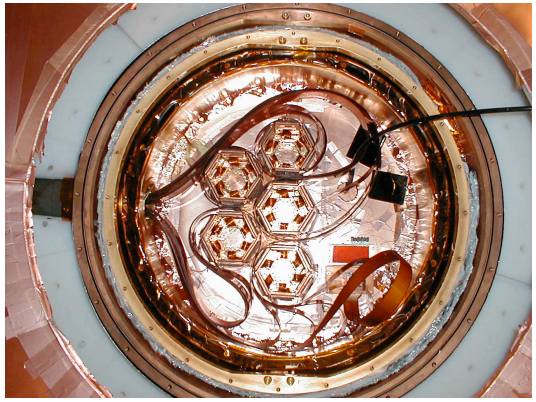
Dilution Refrigerator
(< 50 mK)



Cryocooler (77K and 4K)
Removes heat load from signal cables.

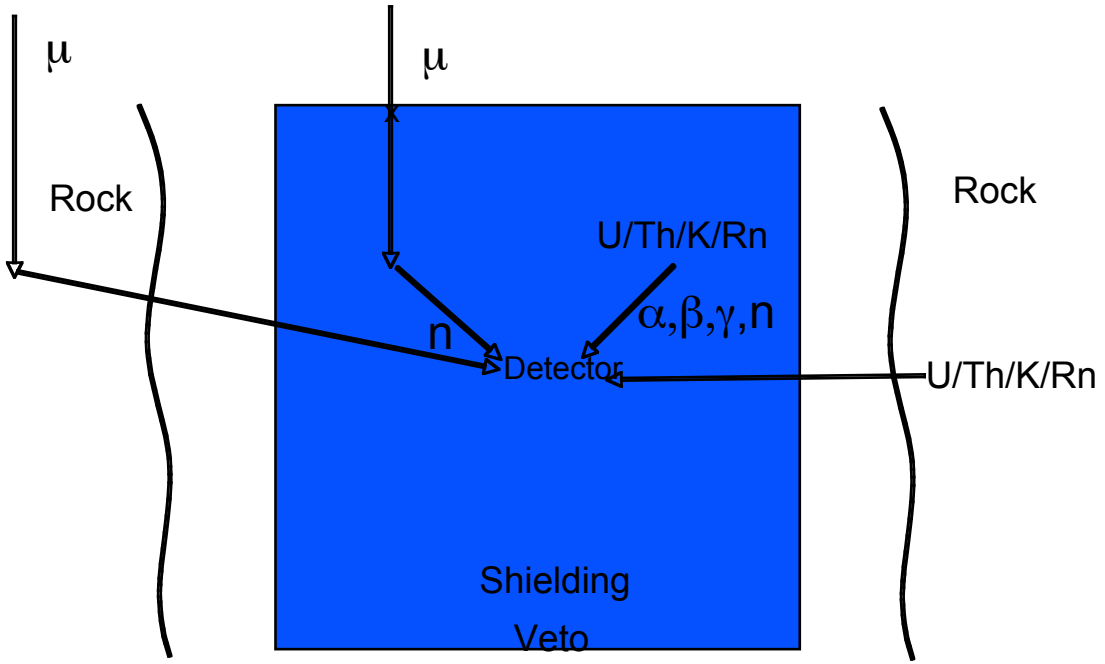


Icebox (Detector Cold Volume)



Backgrounds

- Gammas
  - U/Th/K in surrounding materials
    - Radon especially difficult (22-yr half-life)
    - Clean Pb shielding
- Betas
  - Beta-emitting isotopes on or very near detectors
    - 222Rn, 14C, 3H, 40K,...
    - Ultra-clean handling of detectors, icebox
- Neutrons
  - MeV (fissions, (alpha,n))
    - Polyethylene shielding
  - GeV (cosmic rays)
    - Depth

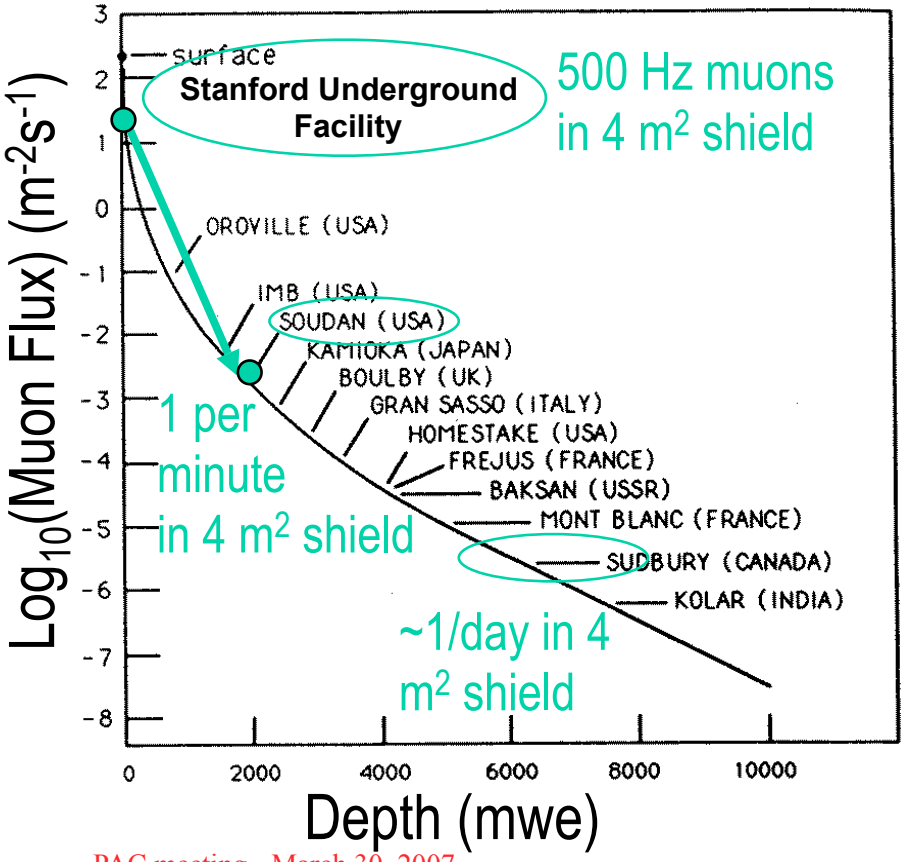


ALL direct detection experiments must reduce these sources of background and also distinguish them from WIMP signals!

Why are we at Soudan?

Depth of 2000 mwe (2341') reduces cosmic-ray-induced neutron background to < 0.1 / kg / year at Soudan => sensitivity to a few WIMPs per year!

Likely to be the limiting background by 2009

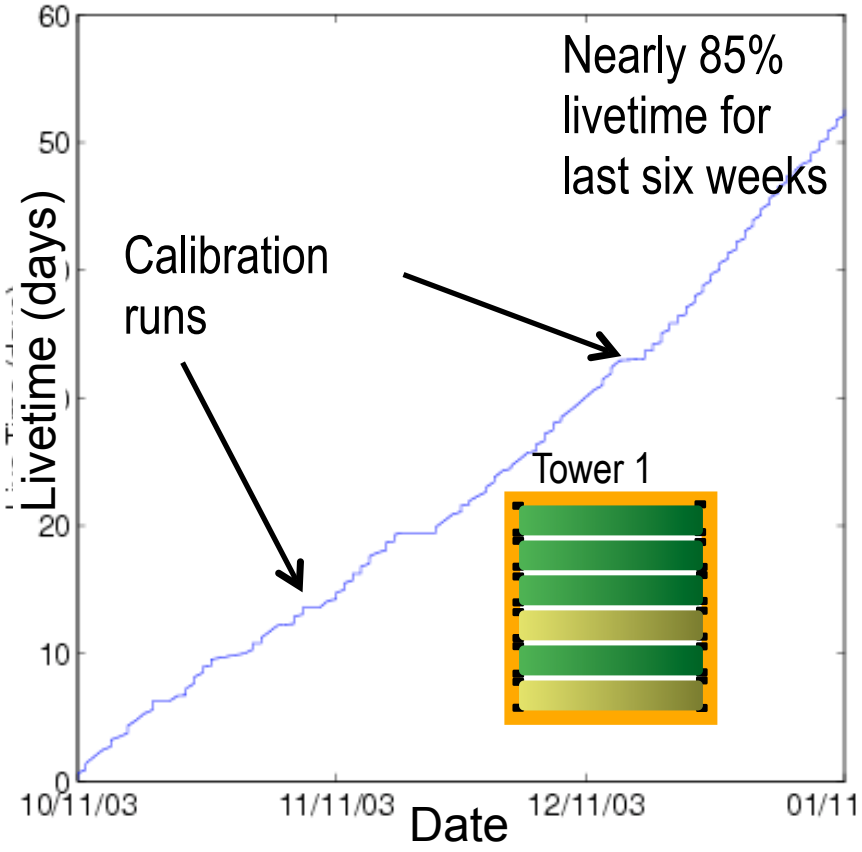


First detectors arriving: winter 2003

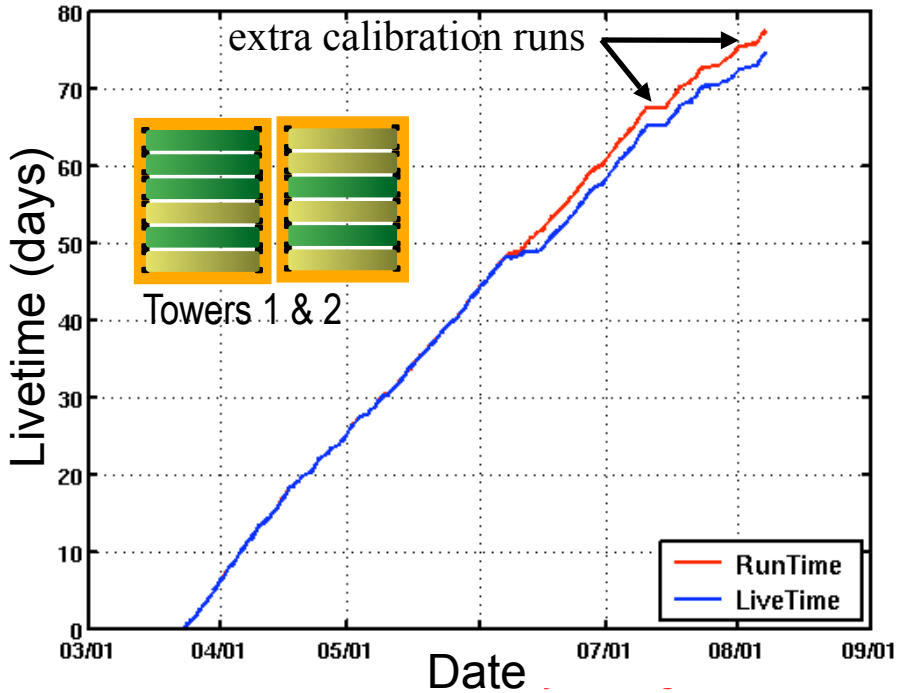
Previous run of CDMS II at Soudan

- October 2003- January 2004 "Tower 1"
  - 1 kg of Ge, 0.2 kg of Si
  - 53 livedays => 53 kg-day Ge

- March-August 2004 "The Two Towers"
  - 1.5 kg of Ge, 0.6 kg of Si
  - 74 livedays => 111 kg-days Ge
  - Nearly doubled exposure, expected sensitivity, and calibration data



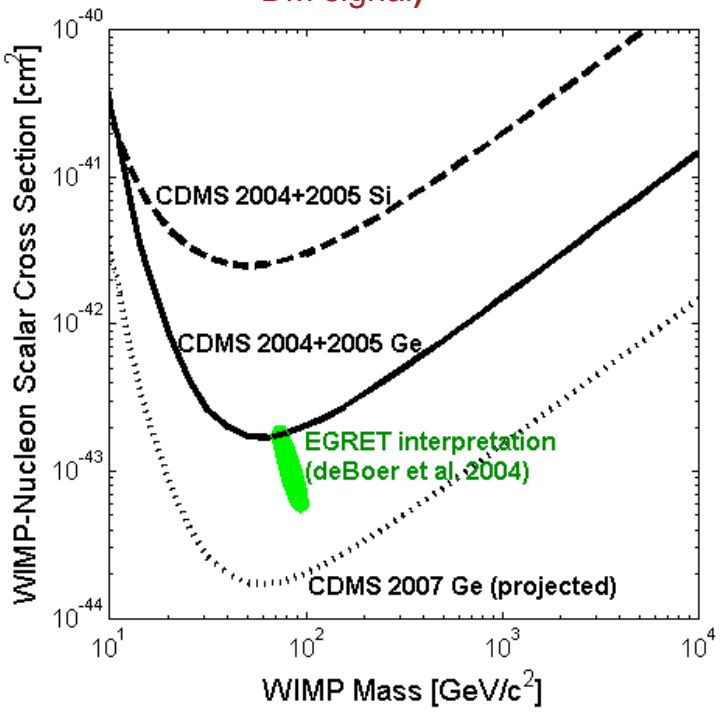
Exposure = Target mass x Livetime
Equivalent to Luminosity for Colliders

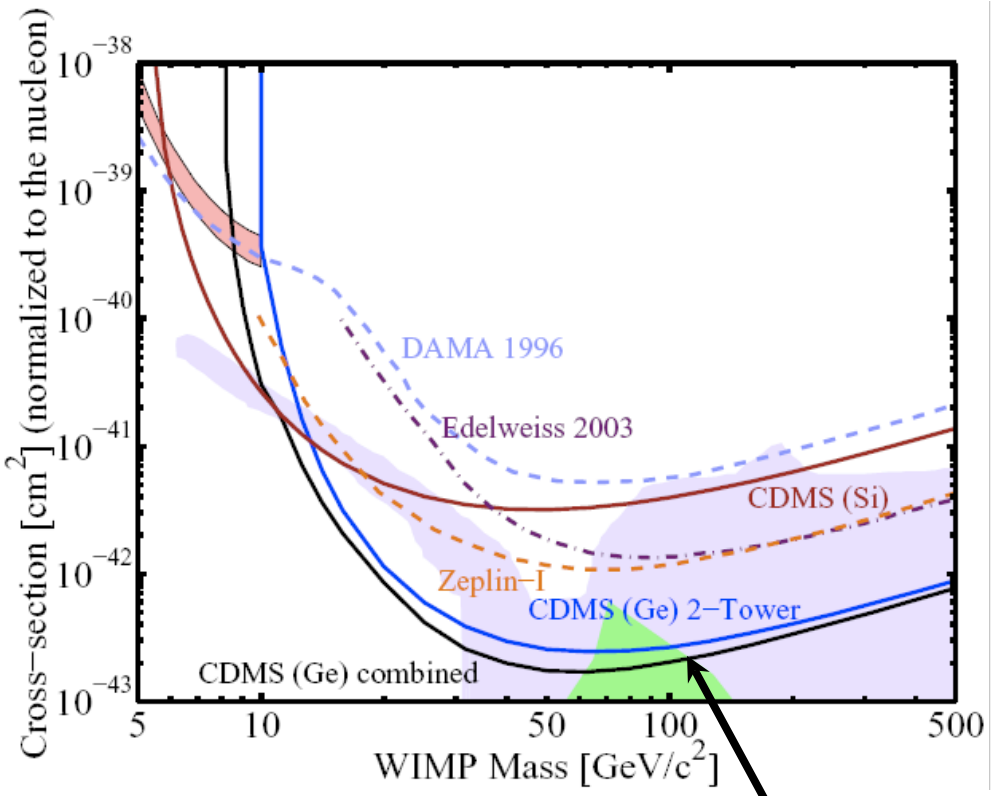


CDMS-II Results for Spin-Independent Interactions

CDMS has the World's Best Limits

DAMA/NaI
Bernabei et al., astro-ph/0307403
(we see no evidence of claimed DM signal)





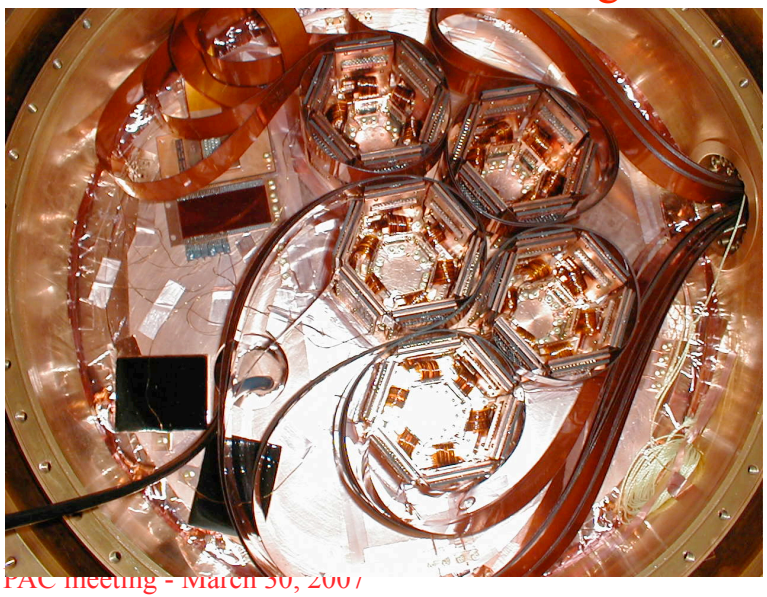
EGRET
de Boer et al., astro-ph/0412620

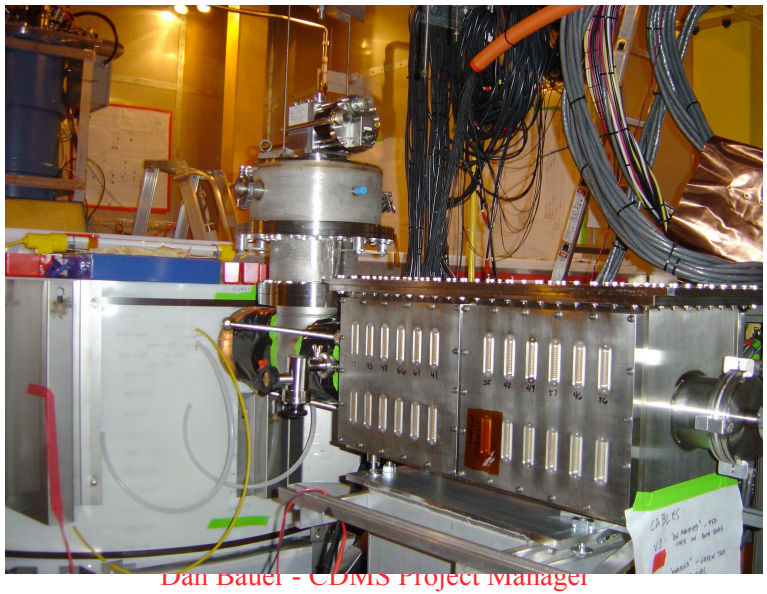
- Cannot yet rule out EGRET gamma ray excess as DM annihilation

For further details see PRL 96, 011302 (2006)

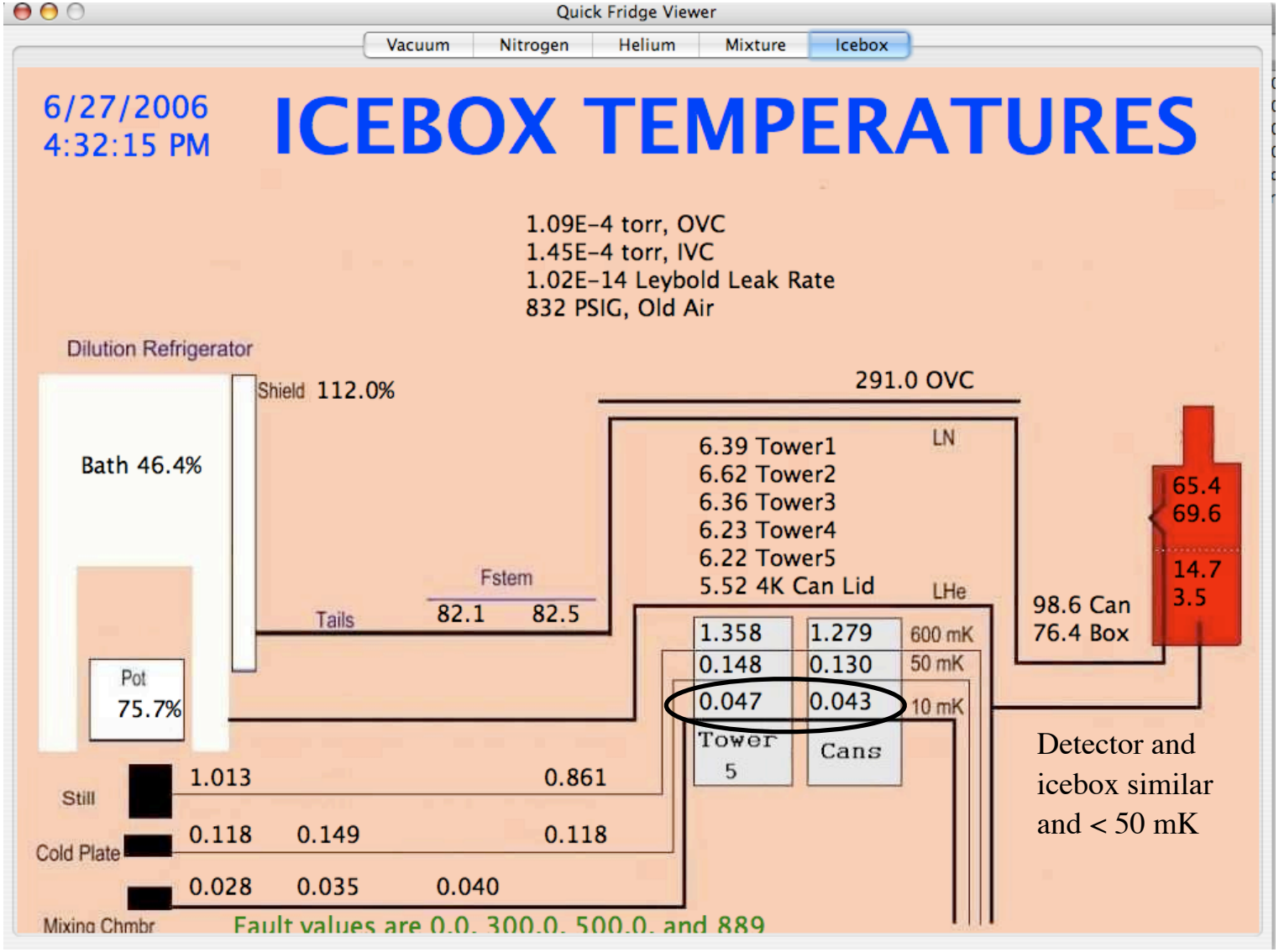
Cryogenic and Detector Upgrades (2005-2006)

- Cryogenics Upgrades
  - Better vacuum to improve stability, decrease maintenance
  - Better control and monitoring, more robust against power outages (UPS and generator installed)
  - Improve cooling at 4K with cryocooler on electronics stem; reduce Lhe consumption, costs; had to deal with vibration problems
- Detectors
  - Three new towers installed; total of 4.5 kg Ge, 1 kg Si
  - Thermal connections to refrigerator improved



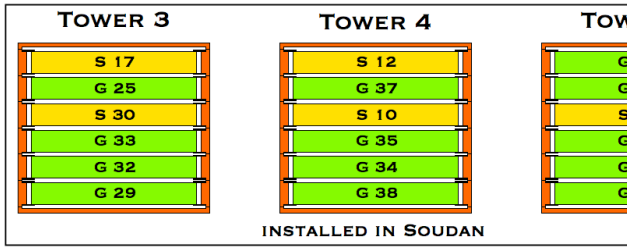


Success in summer 2006! Detectors at 47 mK



Commissioning of the 5 Tower System July-September 2006

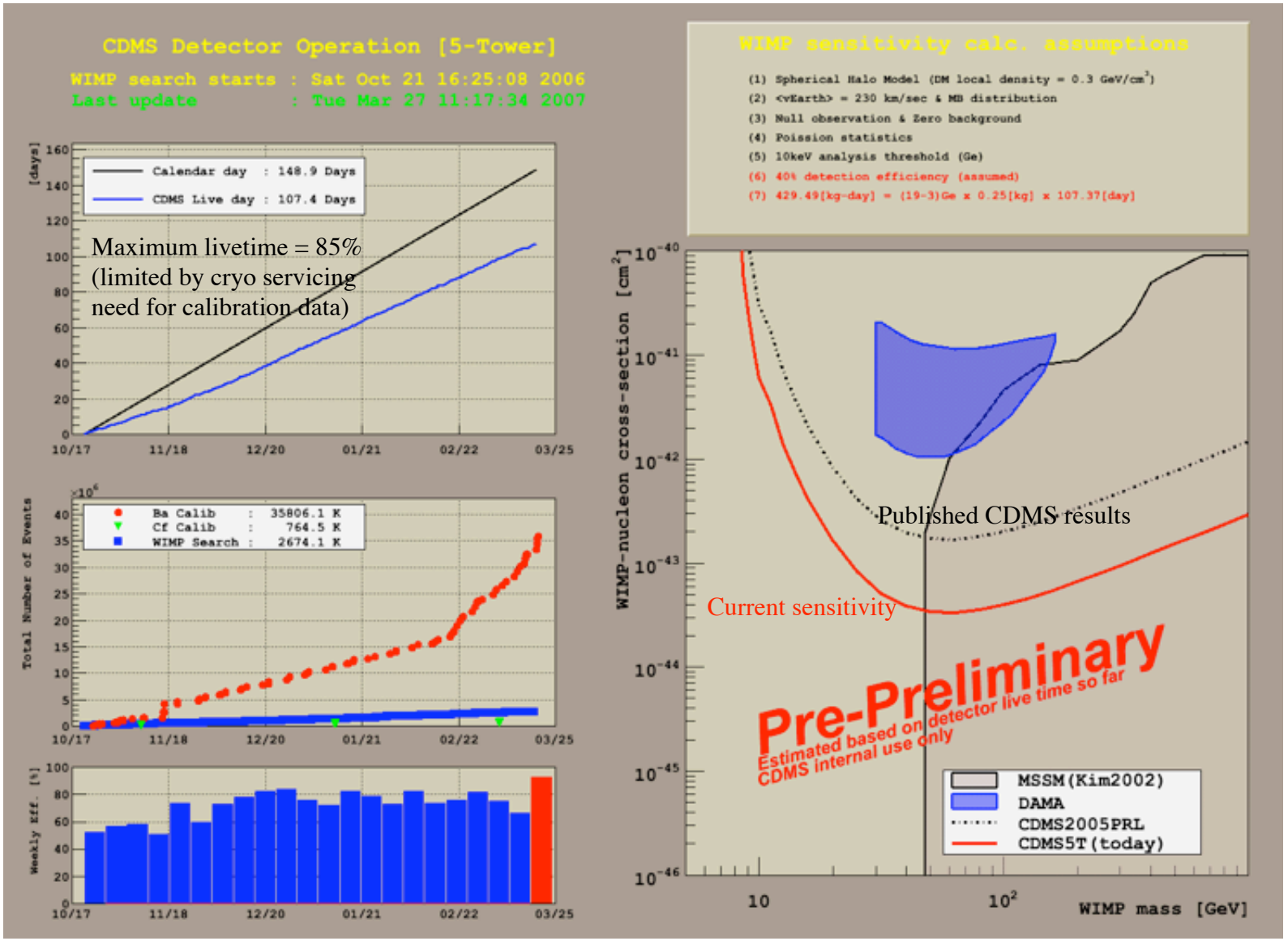
- Detector Tuneup
  - Optimize SQUID, TES settings
  - Neutralize crystals with LEDs
  - LOTs of calibration data
- DAQ and online analysis
  - Handle 80 Hz calibration rate
  - Robust data pipeline to surface
  - Near realtime analysis for data quality monitoring
- Electronic noise reduction
  - Systematic work to eliminate unnecessary grounding
  - Eliminate a few strong source sof RF (cordless phones)
  - Reduce 60 Hz harmonics



Data run with 5 towers
October 2006 - March 2007

- Vital statistics
  - Base temperature for ~ 9 months
  - 5 months of high-efficiency data taking (**430 kg-days Ge**)
    - 107.4 live days for WIMP search (2.7 million events)
    - 36 million gamma calibration events
    - 0.76 million neutron calibration events
    - 4 TB of data
- Blind analysis underway
  - Cuts set using calibration data
  - Expect to open nuclear recoil region this summer
  - Present results at fall conferences
  - Sensitivity should be at least x3 better than present

Current Run Summary



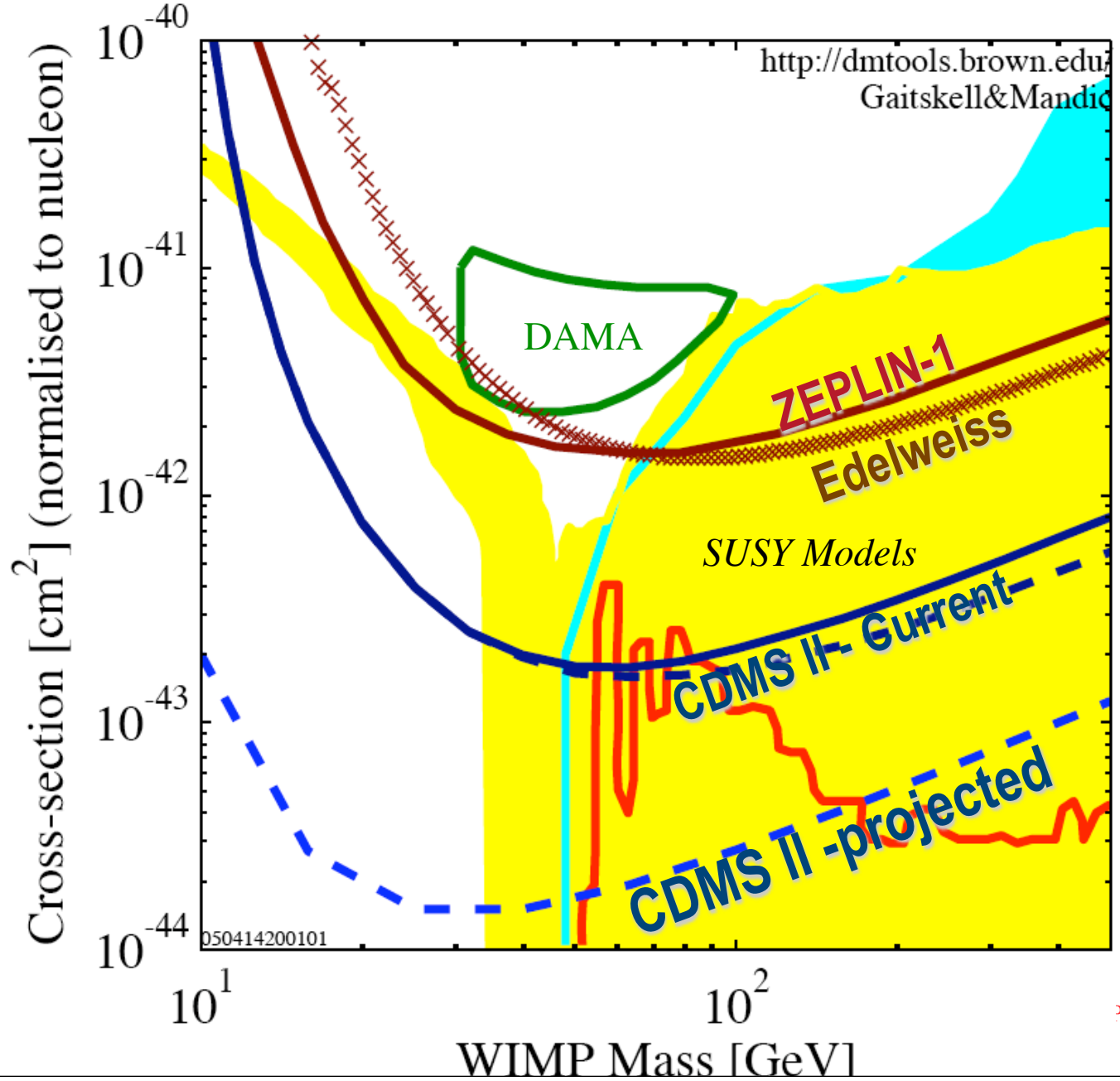
Take a short break for maintenance

- Warmed up to 4K last week
  - Service vacuum pumps, clean 3He/4He mixture
- Successfully reached base temperature again this morning
  - Addressing some low-level electronics noise (60 Hz)
  - Do some minor detector retuning, electronics replacements
  - Adding additional UPS backup (for thunderstorm season)
- This work should prepare us for another long stable run

Second data run with 5 towers
April 2007 - April 2008

- Aim for another x3 improvement in sensitivity (~1200 kg-d)
  - Combined x10 better than present limits
  - Or perhaps we might start to see signal
- May start to run into backgrounds at Soudan in 2008
  - Beta backgrounds on some detectors
  - Neutrons from cosmic rays
- If background-free, run 5 towers into 2009
  - If SuperCDMS detectors ready, run them first in Soudan

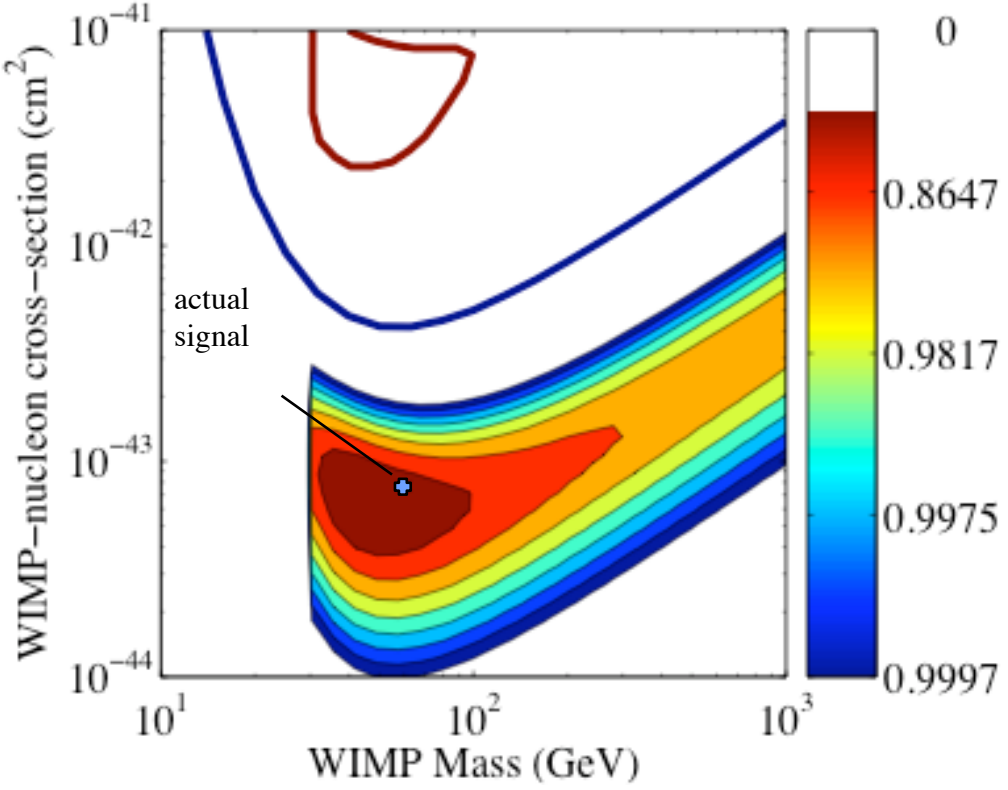
The Future of CDMS at Soudan



Project Manager

What do we learn if we see a signal?

- Current 90% C. L. limit corresponds to < 1 evt per 8 kg-d for Ge
- Most favorable of linear collider SUSY models (LCC2) predicts ~5 events in CDMS II at Soudan!
- WIMP mass & cross section would be determined as shown and SI vs SD determined from different targets



SuperCDMS 25 kg would be ideal for exploring such a WIMP signal on the same time scale as LHC!

Fermilab responsibilities in CDMS II

Established roles in CDMS

Project Management

Project Manager, Financial support people

Operations

Lead the Soudan operations on both physicist and technical sides

Cryogenics

Lead the design, construction and testing of the cryogenics systems

Electronics, DAQ, Computing

Warm electronics, event builder software, online and offline processing

Infrastructure

Clean rooms, control rooms, computing rooms

Analysis

Independent analysis chain (based on ROOT, time-domain pulse fitting)

New Fermilab responsibilities in SuperCDMS

New roles for SuperCDMS

- Backgrounds
  - Collaborating with COUPP on understanding Radon, alpha screening
  - May get involved in beta screening with new clean TPC
- Shield/Veto
  - Do mechanical design and construction together with cryogenics
- Detectors
  - Exploring possibilities for automated inspection and repair at SiDet
  - May also get involved in bonding our sensors to larger crystals
- Systems Test
  - Put everything together at Fermilab and test before taking to SNOLAB

Need more scientist and engineering help to push forward these new areas

CDMS budget summary

CDMS II

- Project budget = $18.5M (6 years)
- Total budget including base funding = $29.5M
- Most of the operations funding comes from Fermilab
  - Currently ~$0.5M M&S, $1.3M Labor

SuperCDMS

- Project budget = $16.2M (6 years)
- Total budget including base funding = $47.3M
  - Increased base funding at Universities
  - FNAL operations budget growing to maintain both Soudan and SNOLAB