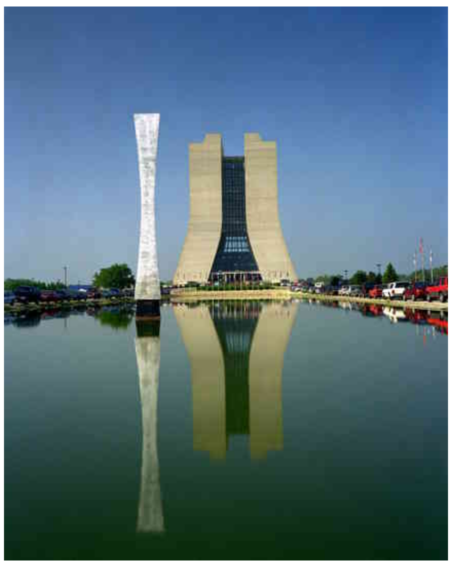
The Search for Dark Matter in Our Universe: CDMS - World's Most Sensitive Experiment



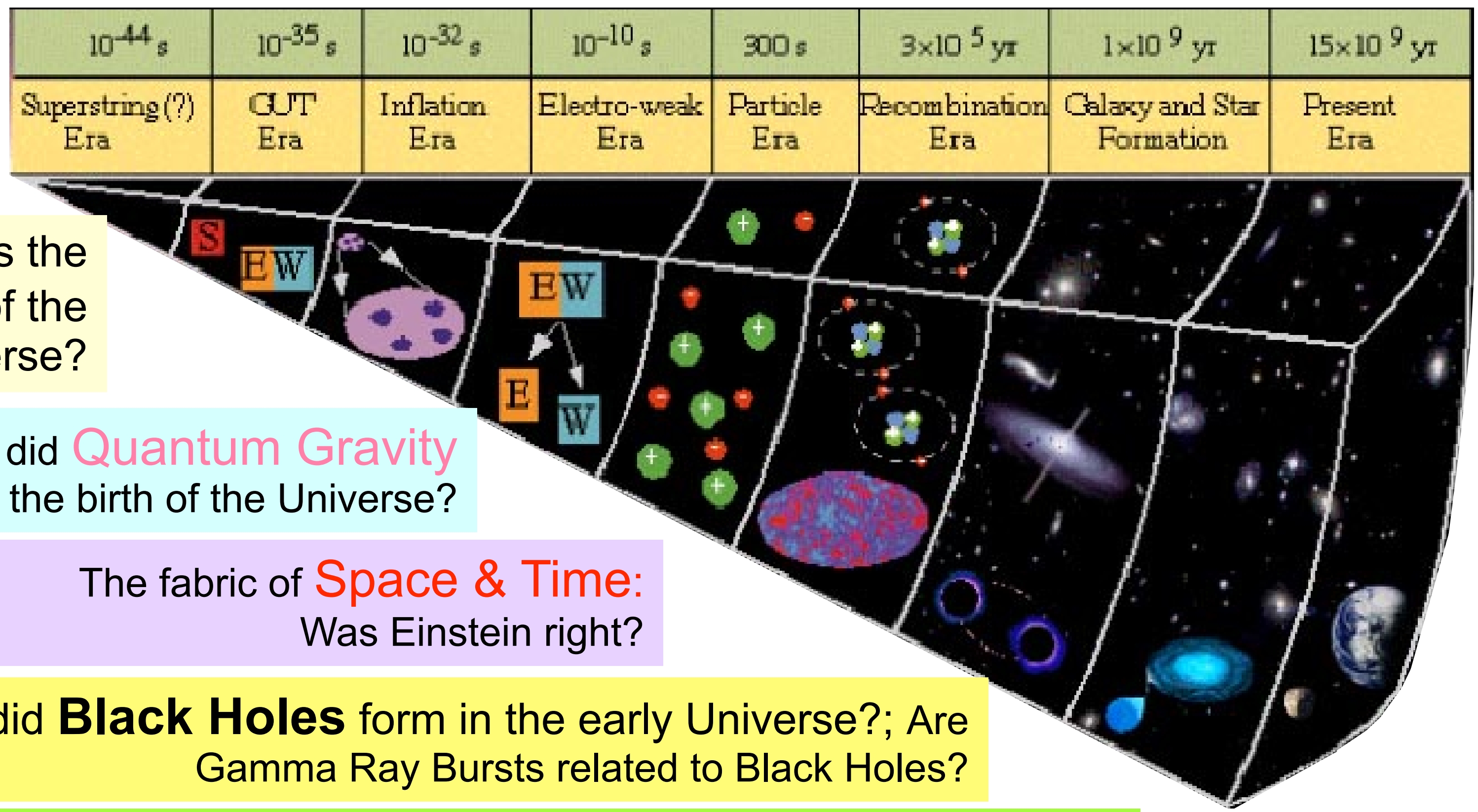
The Witherell Years
Symposium
Fermi National
Accelerator Laboratory
July 14, 2005

Blas Cabrera
Stanford University
For CDMS Collaboration

CDMS Collaboration

The BIG questions

tim



?

What is the Origin of the Universe?

What role did Quantum Gravity play in the birth of the Universe?

The fabric of Space & Time: Was Einstein right?

How did **Black Holes** form in the early Universe?; Are Gamma Ray Bursts related to Black Holes?

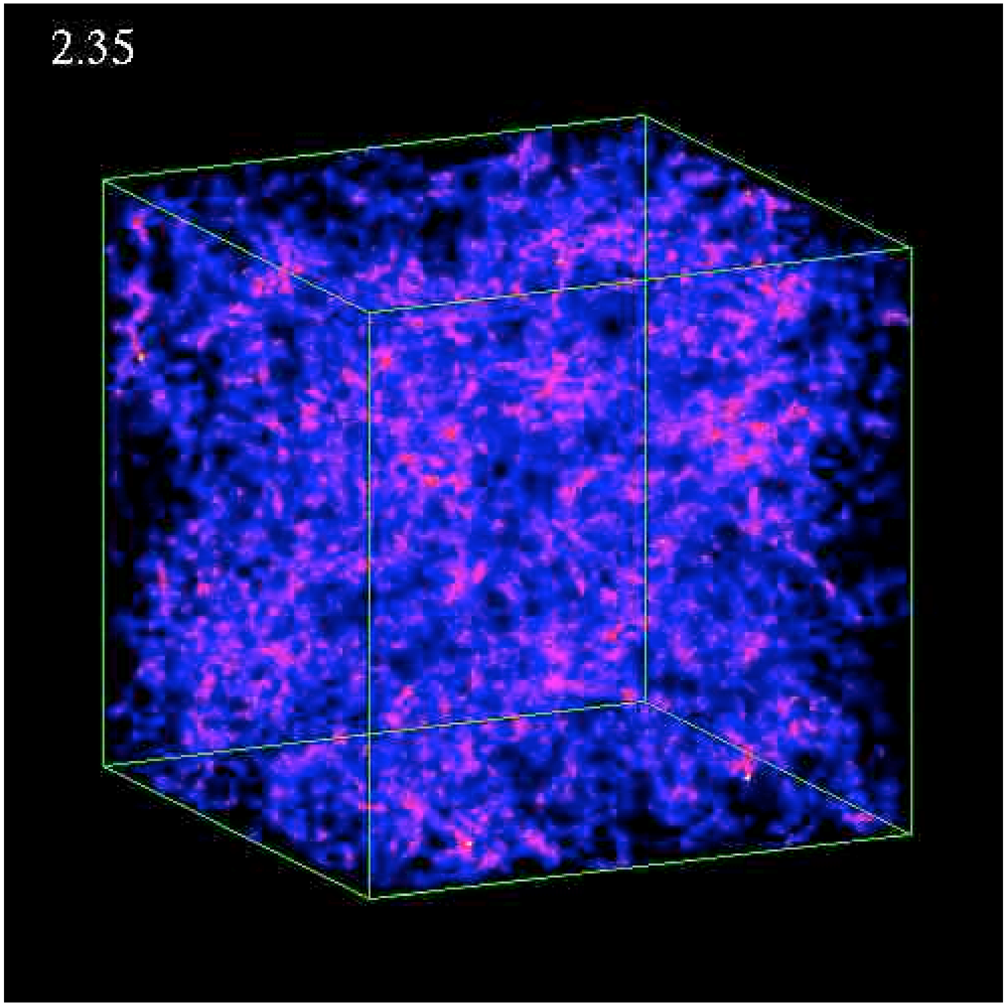
What is **Dark Matter**? Does **Dark Energy** really exist?

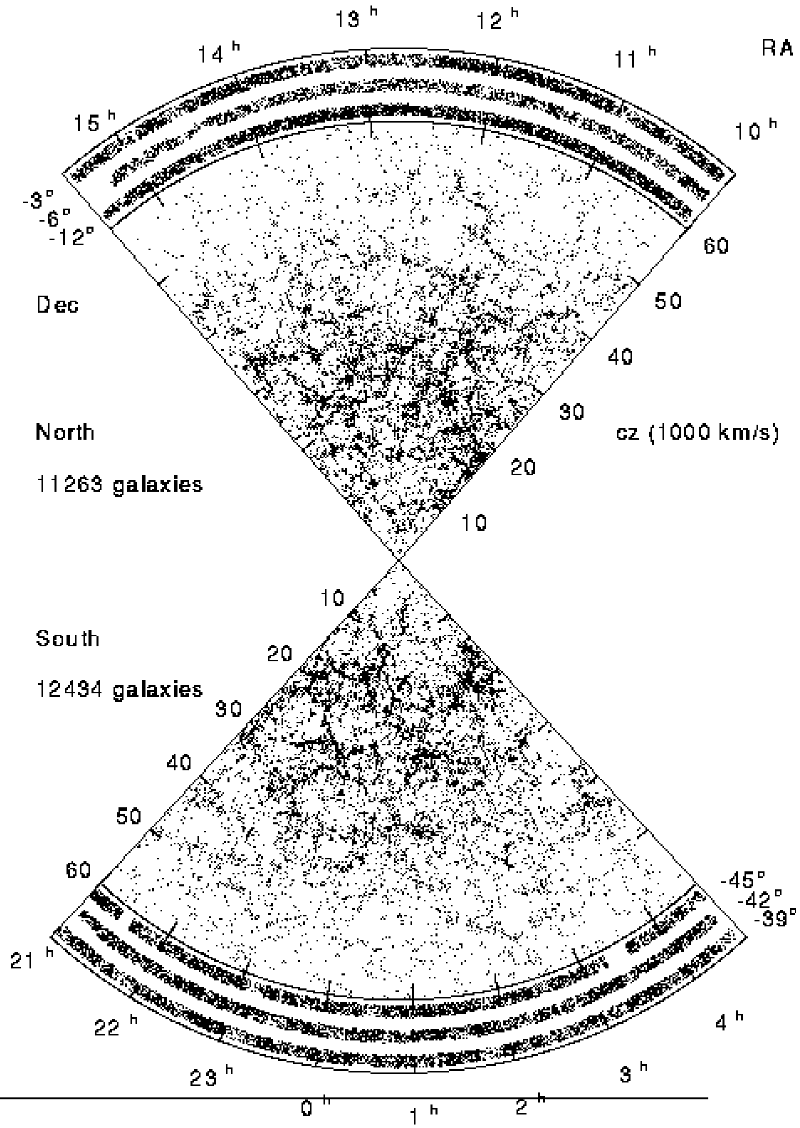
How did **Galaxies** form? Which came first, Black Holes or Galaxies?

How does our star work? Is **Life** in our galaxy unique?

What is the ultimate fate of the Universe?

Expanding universe - simulations and data



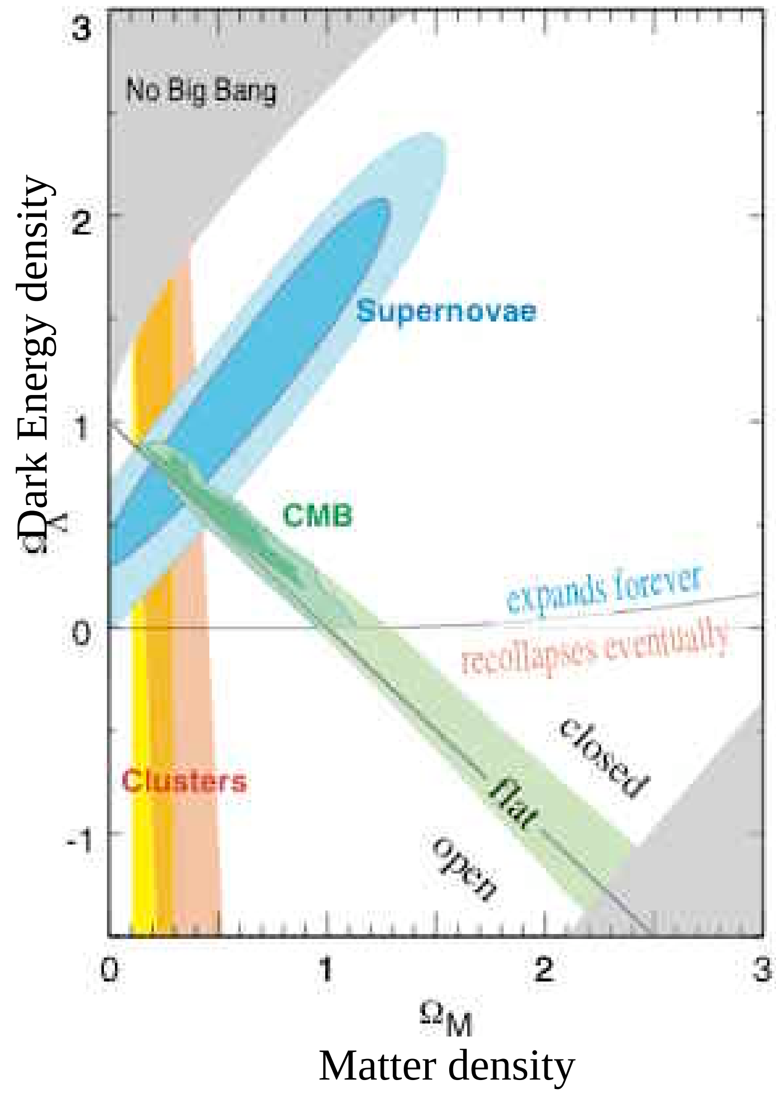


Concordance Model of Cosmology

- Supernovae + Cosmic Microwave Background + Large Scale Structure

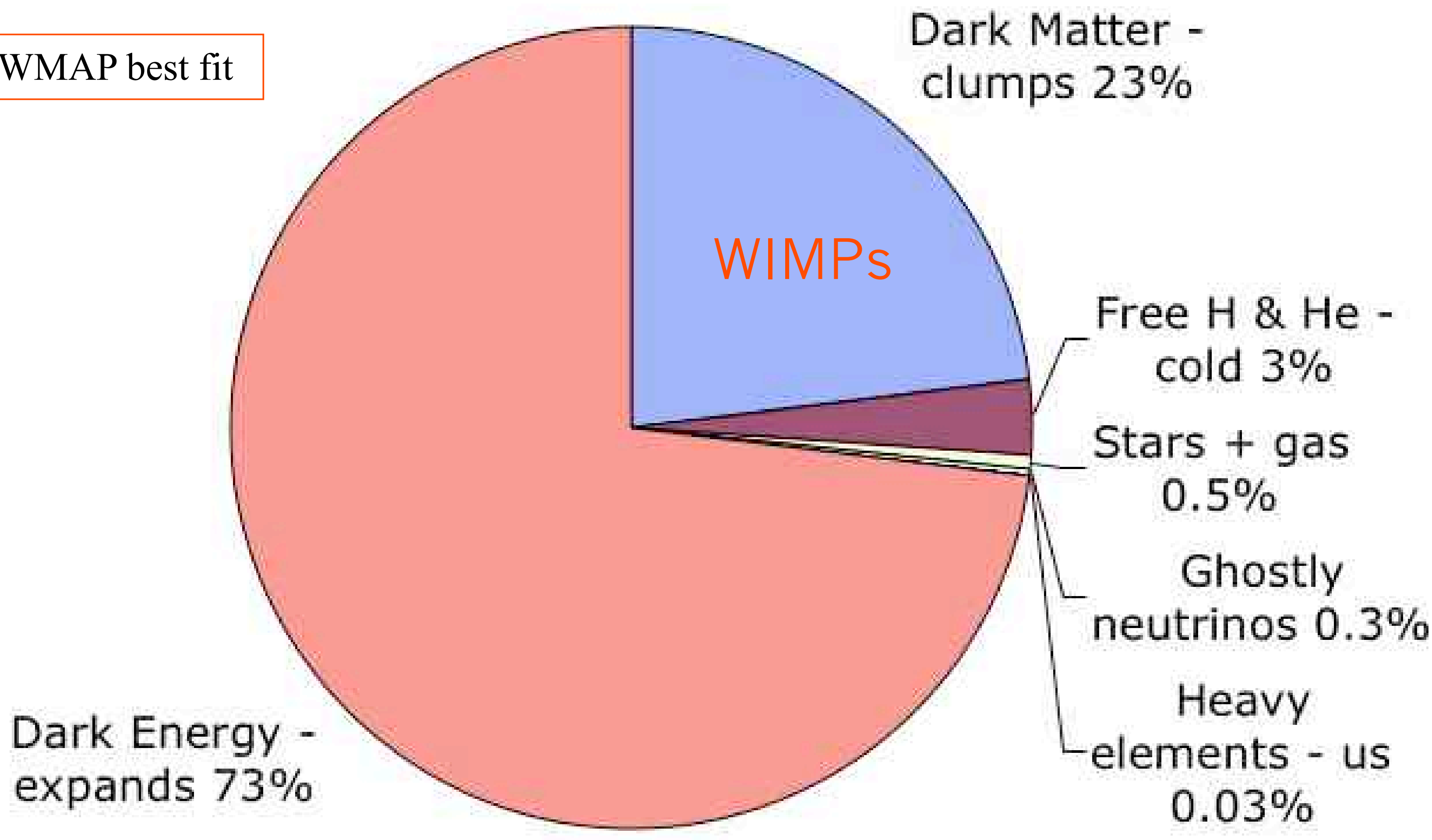
$$\text{WMAP} \; + \text{flat}:$$
$$\forall_m = 0.27 \pm 0.04$$
$$\forall_\# = 0.73 \pm 0.04$$

- Great overall success!
- However raises even more questions about origin of dark energy



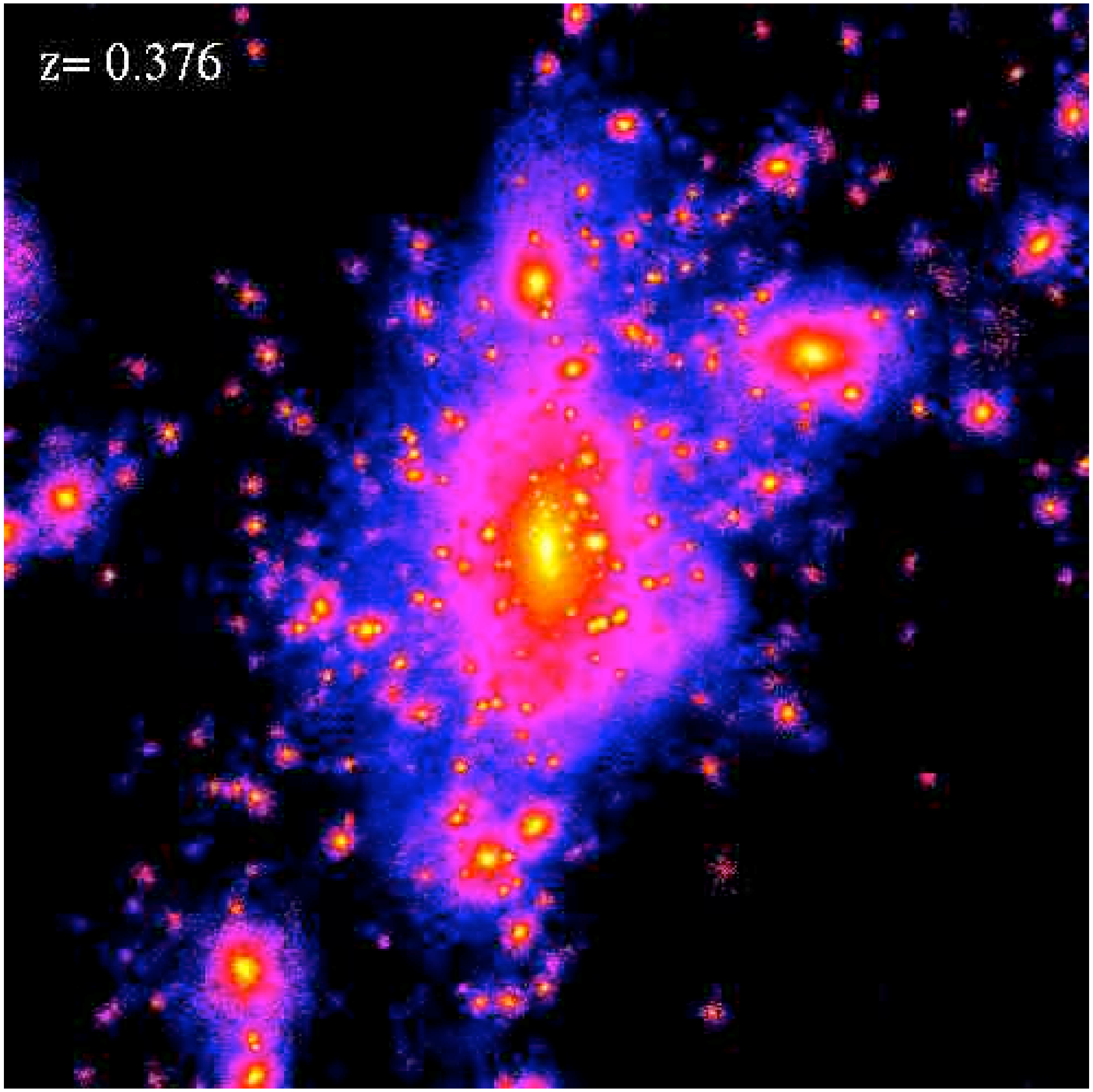
Composition of the Cosmos

WMAP best fit



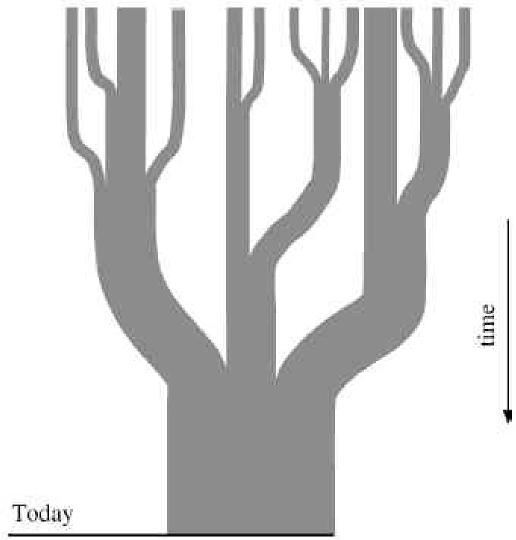
Dark Matter evolution

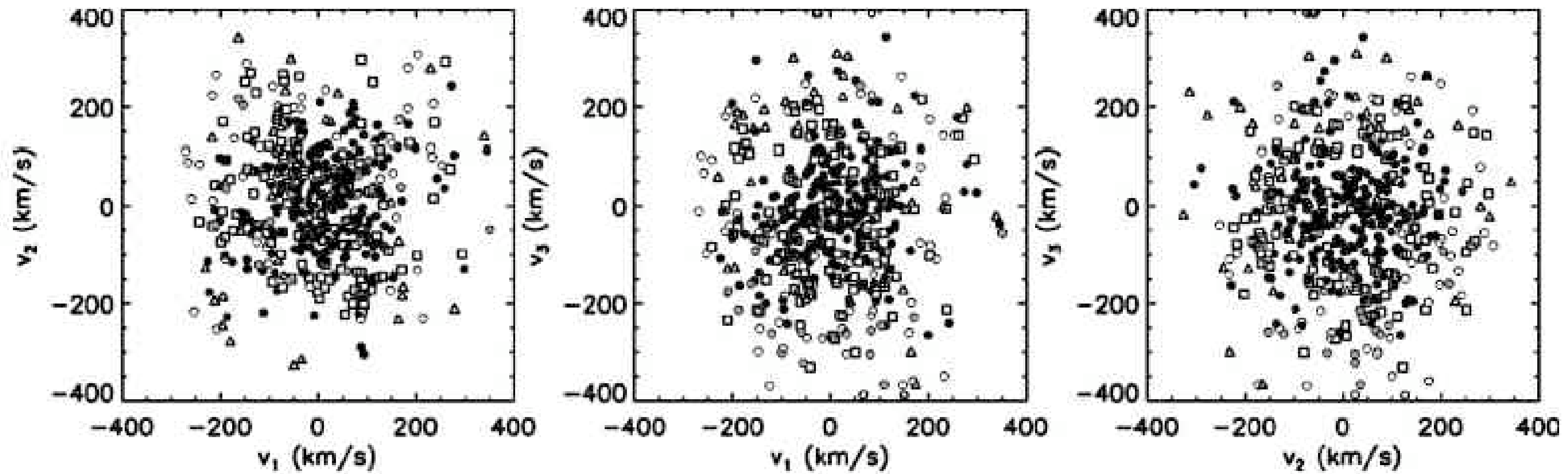
- ! CDM numerical simulations agree well with observations
- Max Planck Institute Munich (Garching)



Numerical simulations

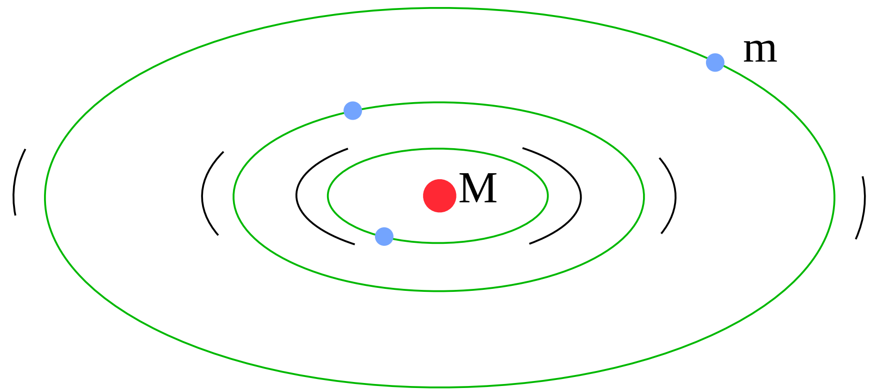
- The phase-space structure of a dark-matter halo: Implications for dark-matter direct detection experiments,
  A. Helmi, S. White, and V. Springel
  PRD 66, 063502 (2002)
- Solar system moves with respect to zero mean velocity halo at 220 km/s





Rotation Curves and Galactic Dark Matter

- Solar System obeys Kepler laws

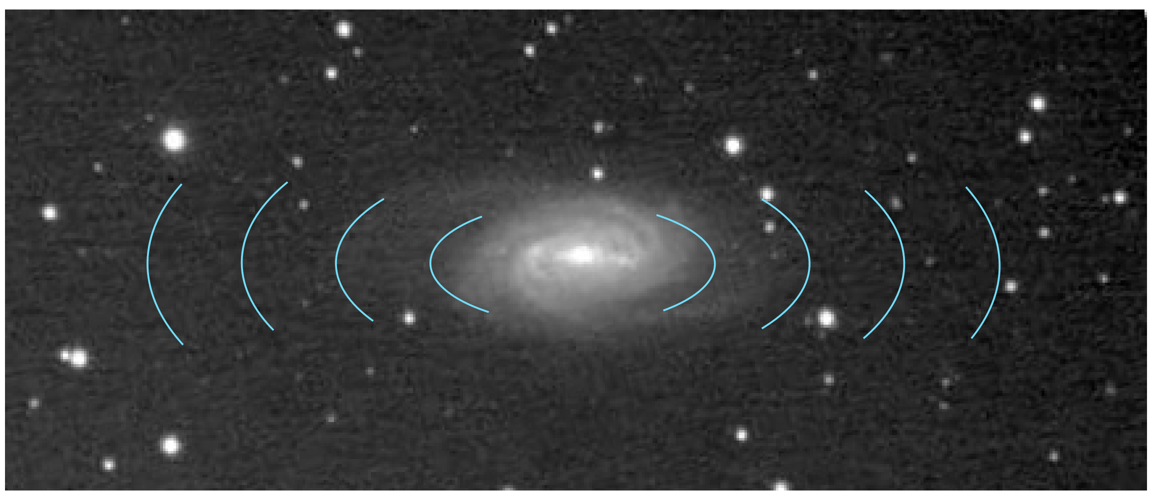


$$\vec{F} = ! \frac{G\,M\,m}{r^2}\hat{r}$$

$$= ! \; m\frac{v^2}{r}\hat{r}$$

$$v = \sqrt{\frac{G\,M}{r}}$$

- Galaxies have constant rotation curves



For :

$v \; ! \;$ constan t

then :

$M(r) \forall \, r$

$M_{dark} \; \# \; 10 M_{lum}$

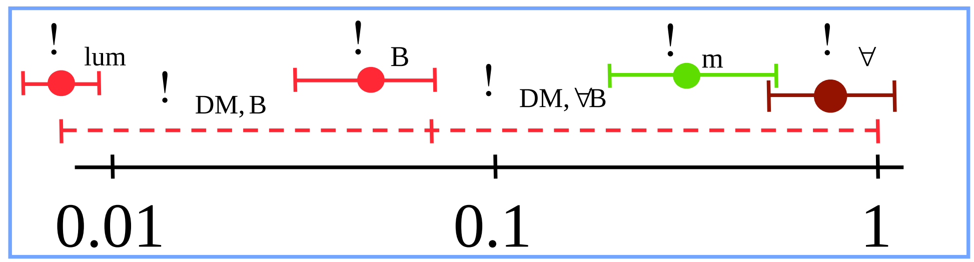
Strong motivation

- Cosmology
  - Theory: $! / !_{crit} = \forall_m;\ \ \forall_m + \forall_\# = 1;\ \ \forall_\# \exists 0$ still ugly!
  - Observation: $0.25 \forall \#_m < 0.30$

But favored by supernova data

- Nuclear Physics: baryons - p, n, e
  - Theory of formation of H, D, He, Li
  - Observations:

    $$0.03 < \forall_B < 0.05$$



- Astronomy: luminous matter
  - Stars & gas $\forall_{lum} \# 0.005$
- Baryonic dark matter is necessary: MACHOs at most 20% of halo mass
- Non-baryonic dark matter dominates universe

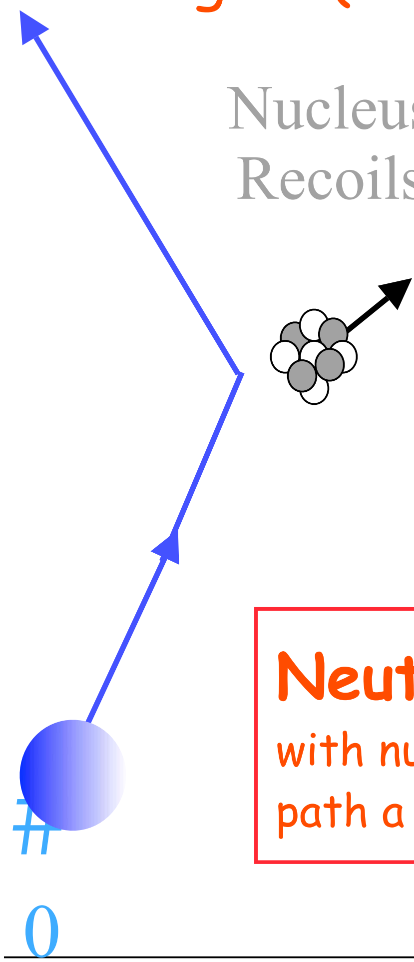
	hot	cold	$\forall$~1
axions		√	√
neutrinos	X		?
monopoles		√	X
WIMPs		√	√ √

best DM candidates

Supersymmetry LSP $\forall = N_{10}^* \tilde{B} + N_{20}^* \tilde{W}^3 + N_{30}^* \tilde{H}_1^0 + N_{40}^* \tilde{H}_2^0$

The Signal and Backgrounds

Signal (WIMPs)



Nucleus Recoils

E
r

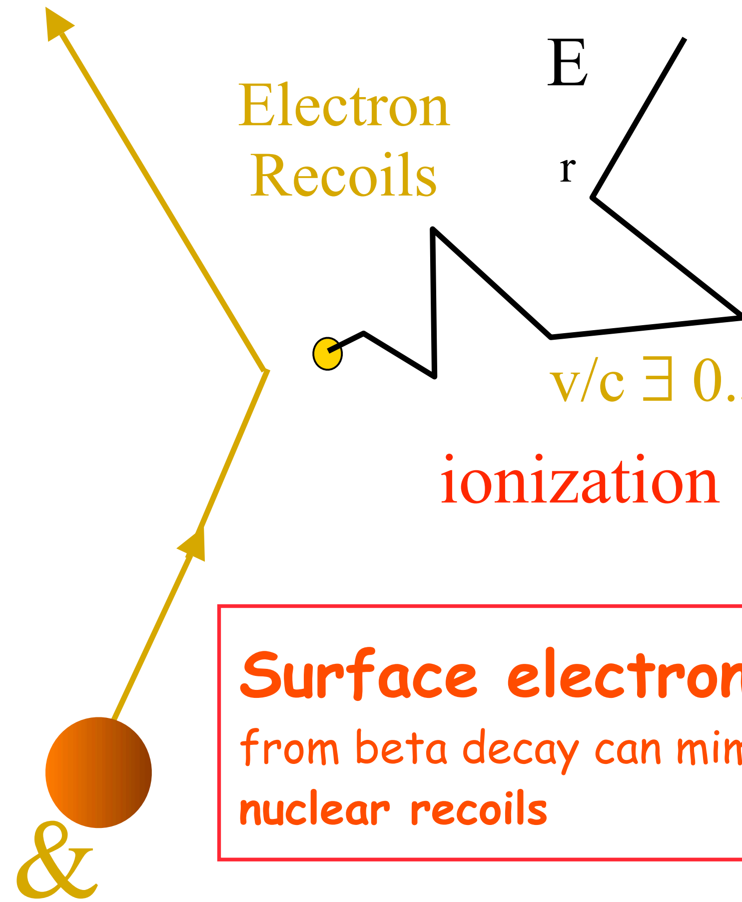
v/c ∃ 7%10^{-4}

E_r ∃ 10's KeV

phonons

Neutrons also interact with nuclei, but mean free path a few cms

Background (gammas)



Electron Recoils

E
r

v/c ∃ 0.3

ionization

Surface electrons from beta decay can mimic **nuclear recoils**

Rule out dark matter nu's & cosmions

- 1988 no 4th nuetrino

t 5 PHYSICAL REVIEW LETTERS

Laboratory Limits on Galactic Cold Dark Matter

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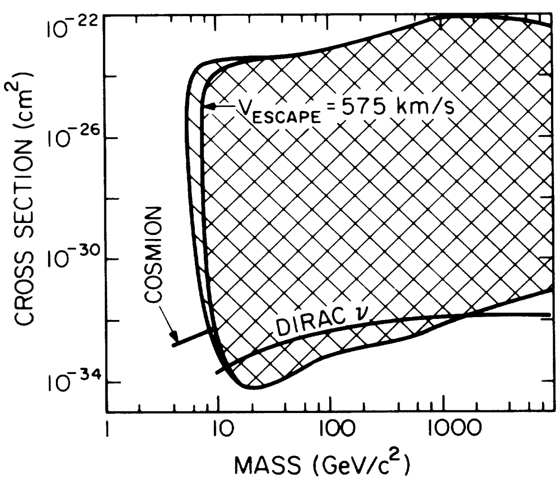
(Received 13 November 1987; revised manuscript received 16 May 1988)



- 1990 no cosmion

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Searching for the Cosmion by Scattering in Si Detectors

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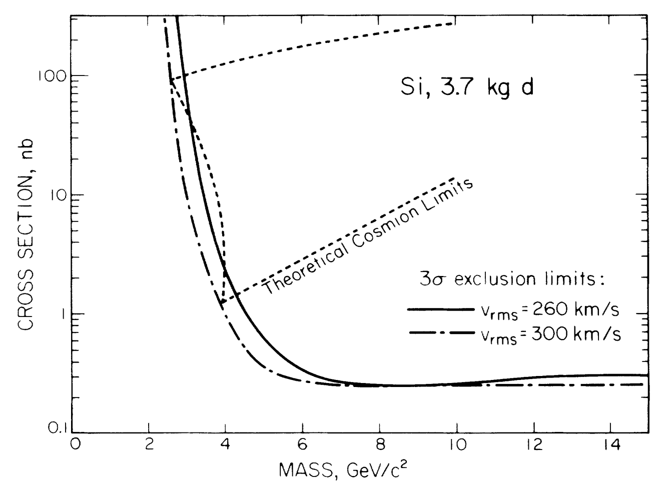
(Received 5 June 1990)



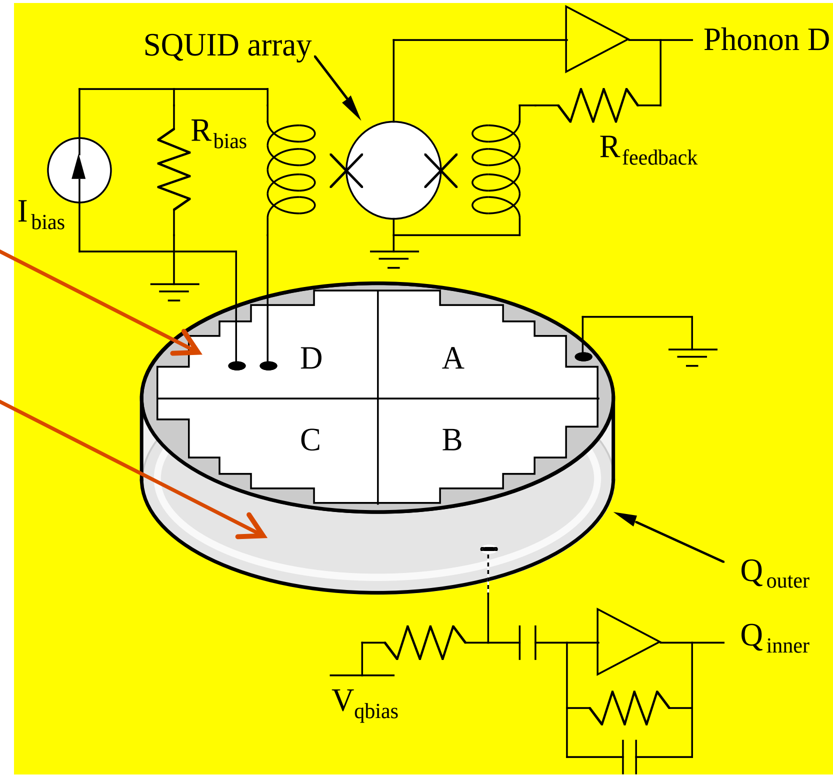
CDMS ZIP Detectors (Ge/Si)

Phonon sensors (4) (TES)

Ionization Electrodes (2)

x-y-z imaging:

from timing, sharing

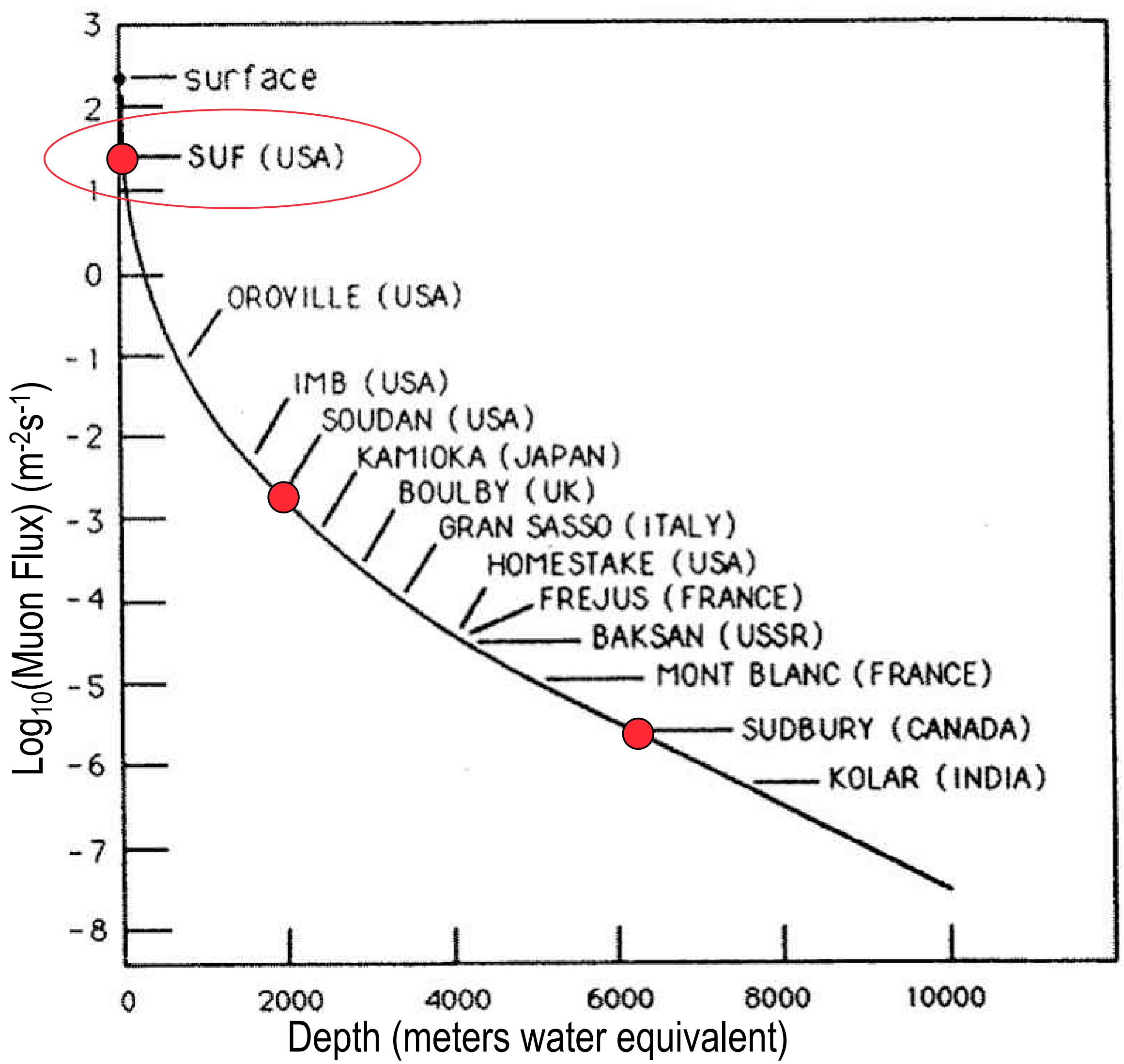


WIMPs: э(Ge) >> э(Si)

Neutrons: э(Ge) (э(Si)

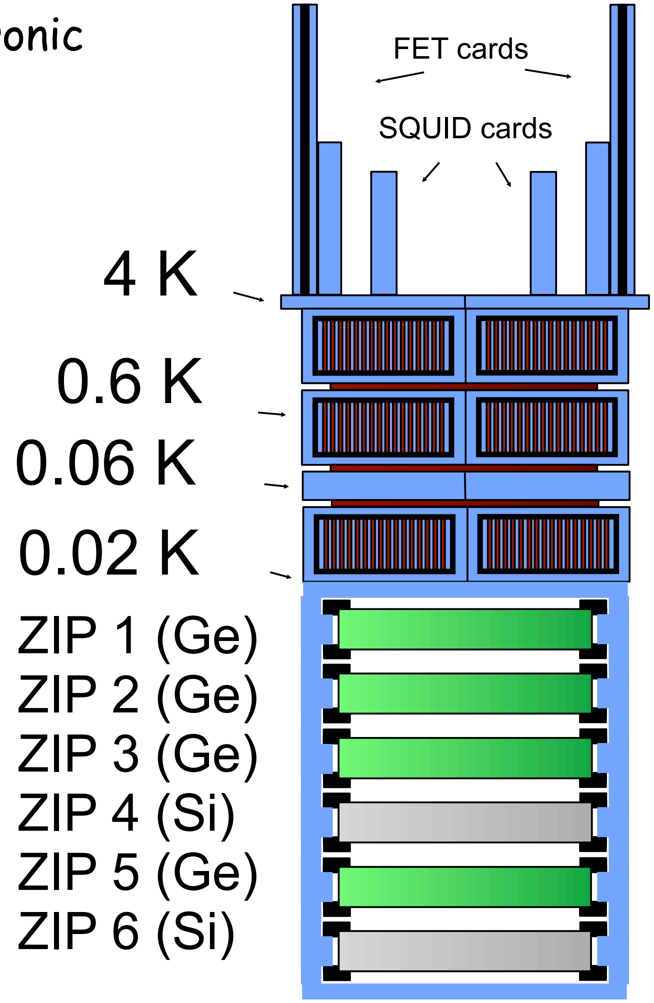
First operate at SUF (17 mwe)

- At SUF
  - 17 mwe
  - 0.5 n/d/kg
- At Soudan
  - 2090 mwe
  - 0.8 n/y/kg
- At SNOLab
  - 6060 mwe
  - 1 n/y/ton

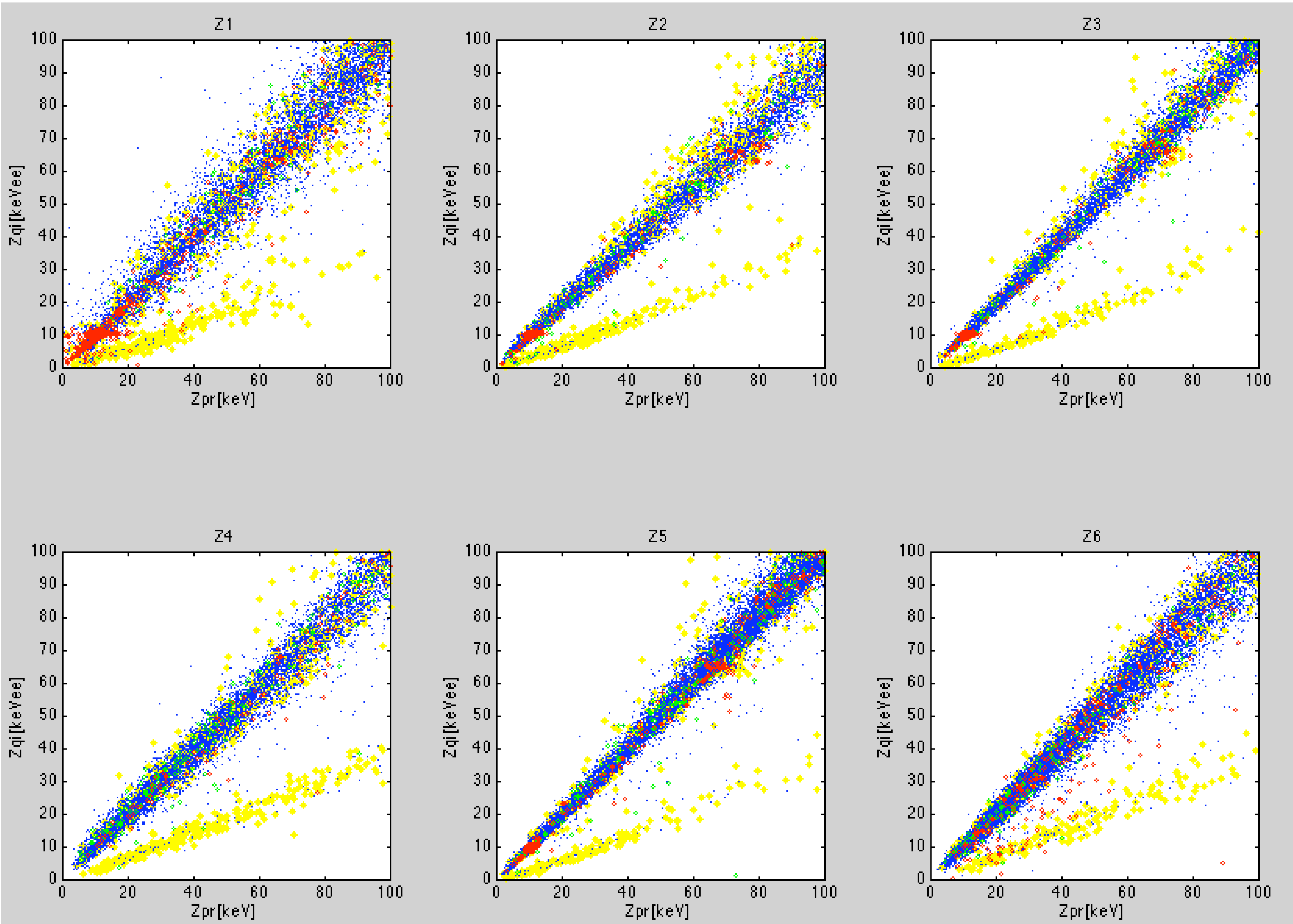


The shallow Stanford Underground Facility (SUF)

- Tower 1 operated at SUF during calendar 2002 at a depth of 17 mwe sufficient to eliminate the hadronic component of cosmic rays



Recoil [keV] vs Charge [keVee]



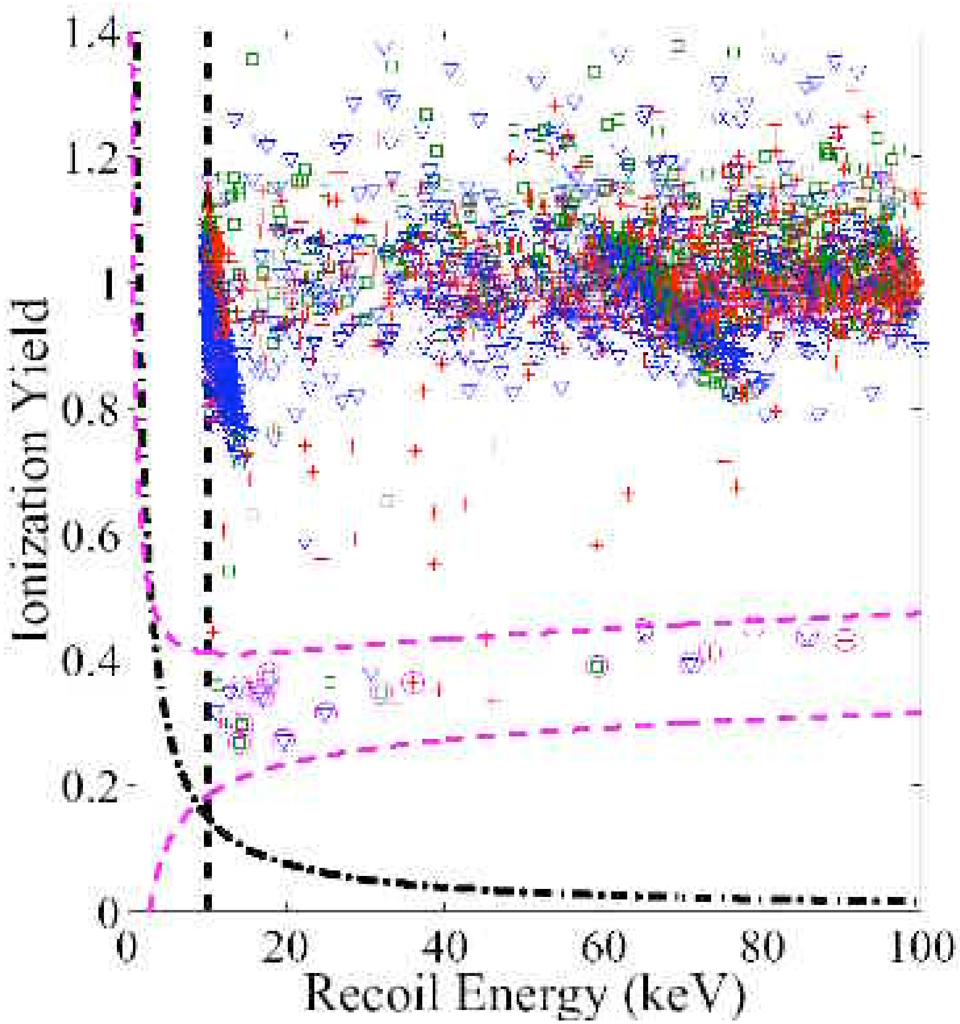
Yellow
^{252}Cf

Blue
μ coin

Red
μ anti

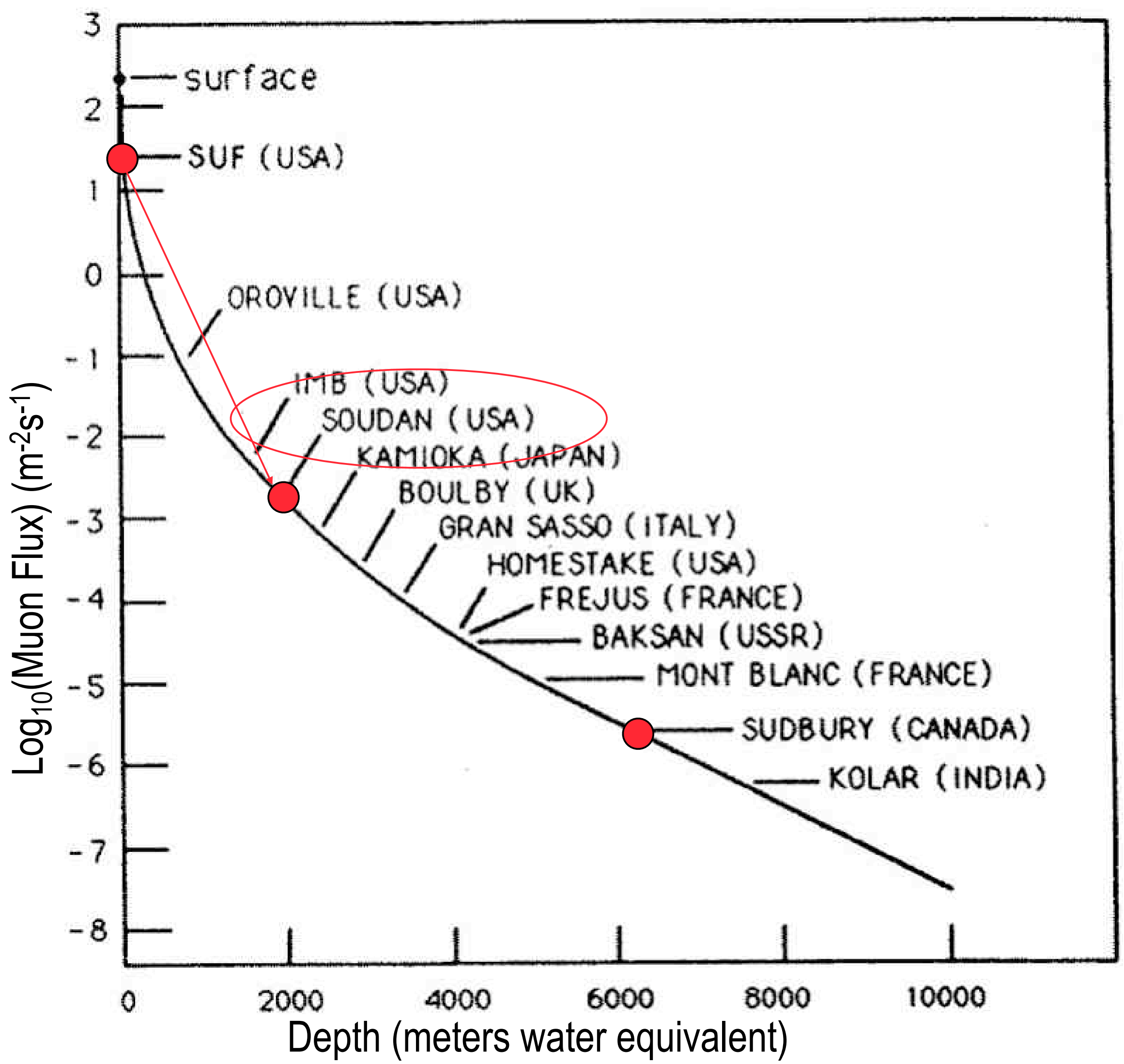
Tower 1 (4 Ge and 2 Si detectors) at SUF

- SUF Run 21
  - Calendar 2002
  - 52.6 kg-d of Ge after cuts
- Saw 19 nuclear recoils
  - clean separation of gamma & beta events
  - See 10 keV and 67 keV lines for energy calibration
- All consistent with neutrons
  - Consistent ratio of Ge singles to Ge multiples
  - Consistent ratio of Ge events to Si events
  - Only gain as sqrt(MT)
- TO DO BETTER NEED TO GO DEEPER

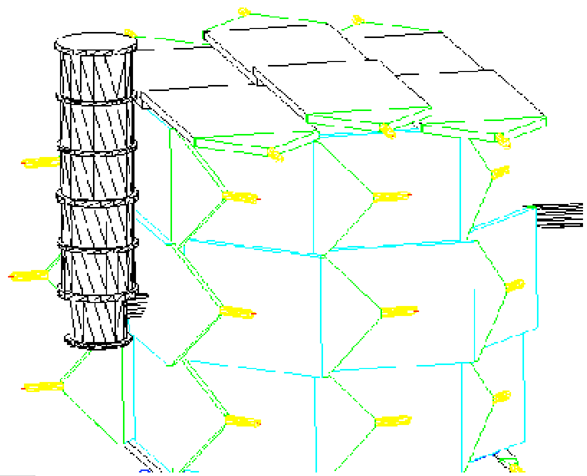


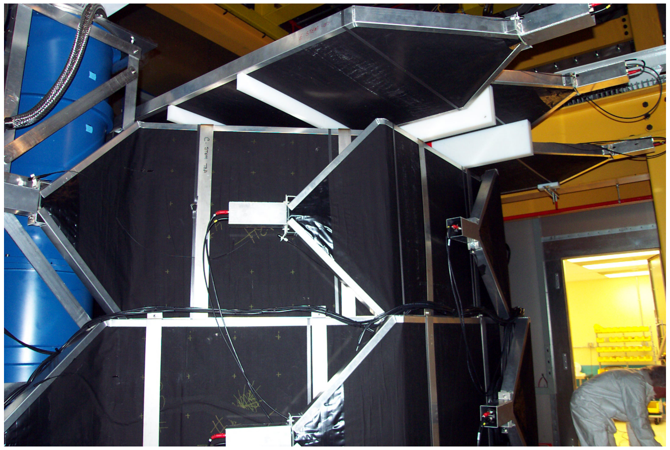
Now operate at Soudan (2090 mwe)

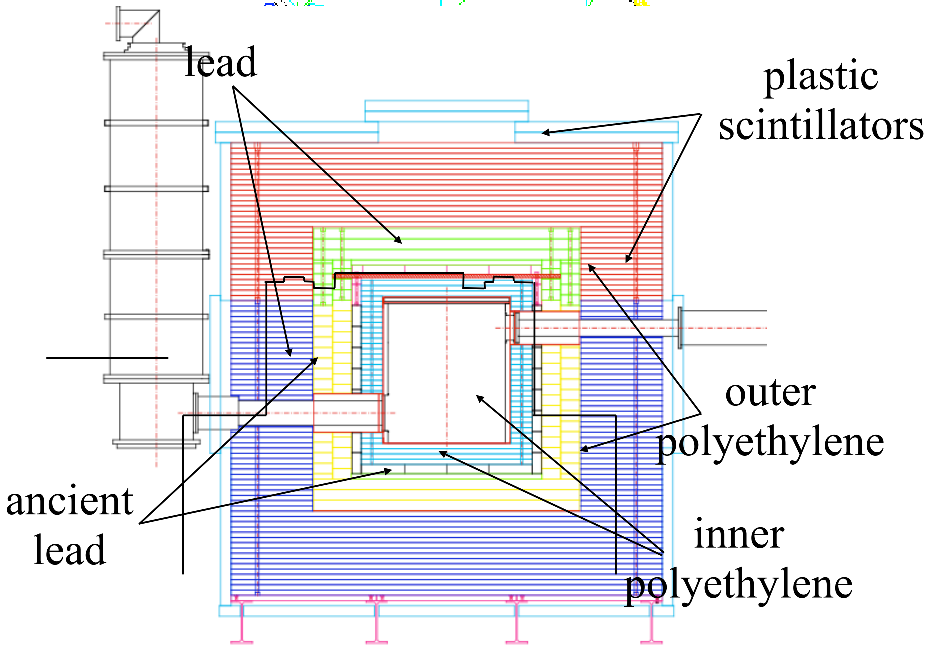
- At SUF
  - 17 mwe
  - 0.5 n/d/kg
- At Soudan
  - 2090 mwe
  - 0.8 n/y/kg
- At SNOLab
  - 6060 mwe
  - 1 n/y/ton



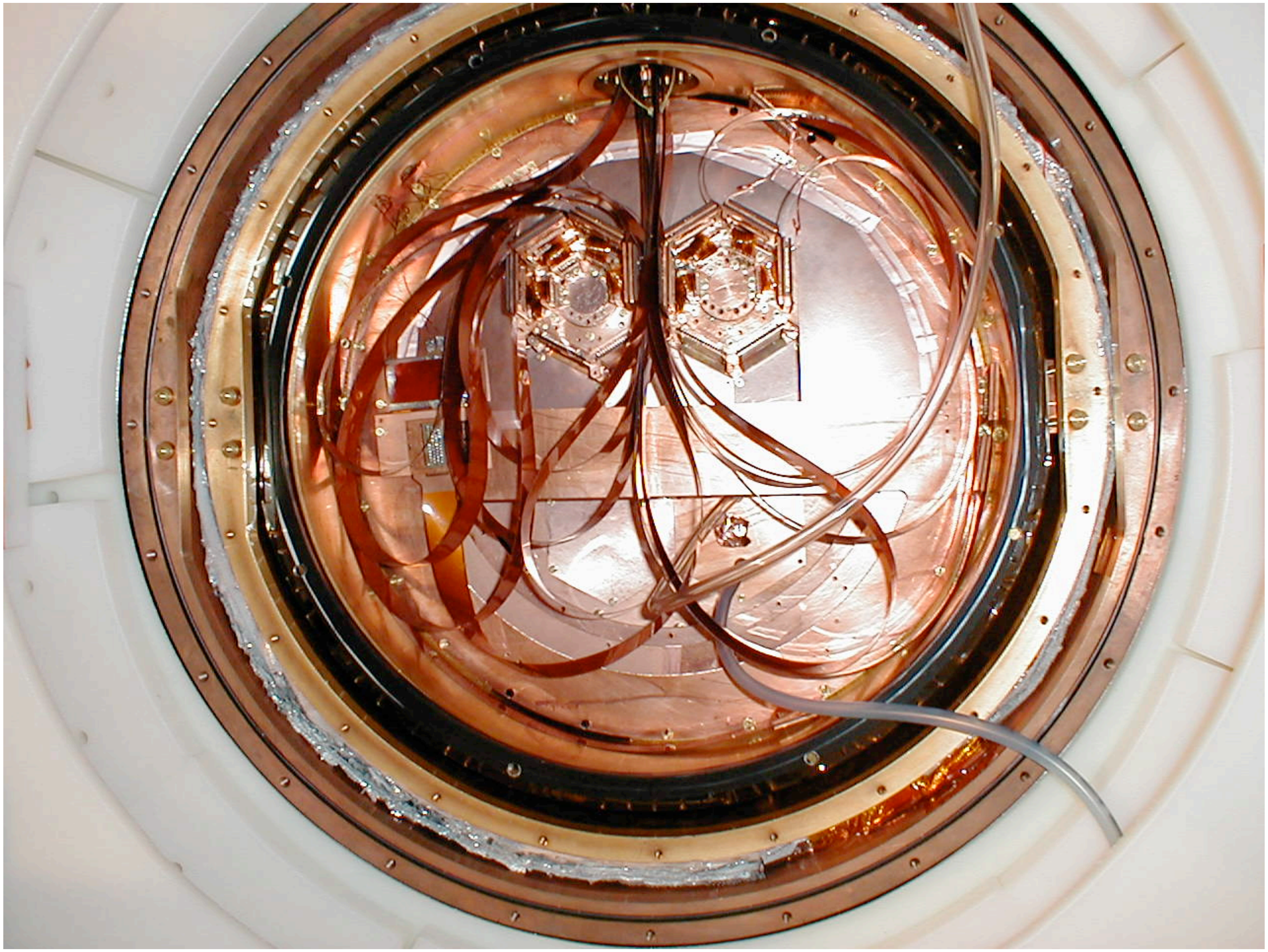
Outside of the Experiment





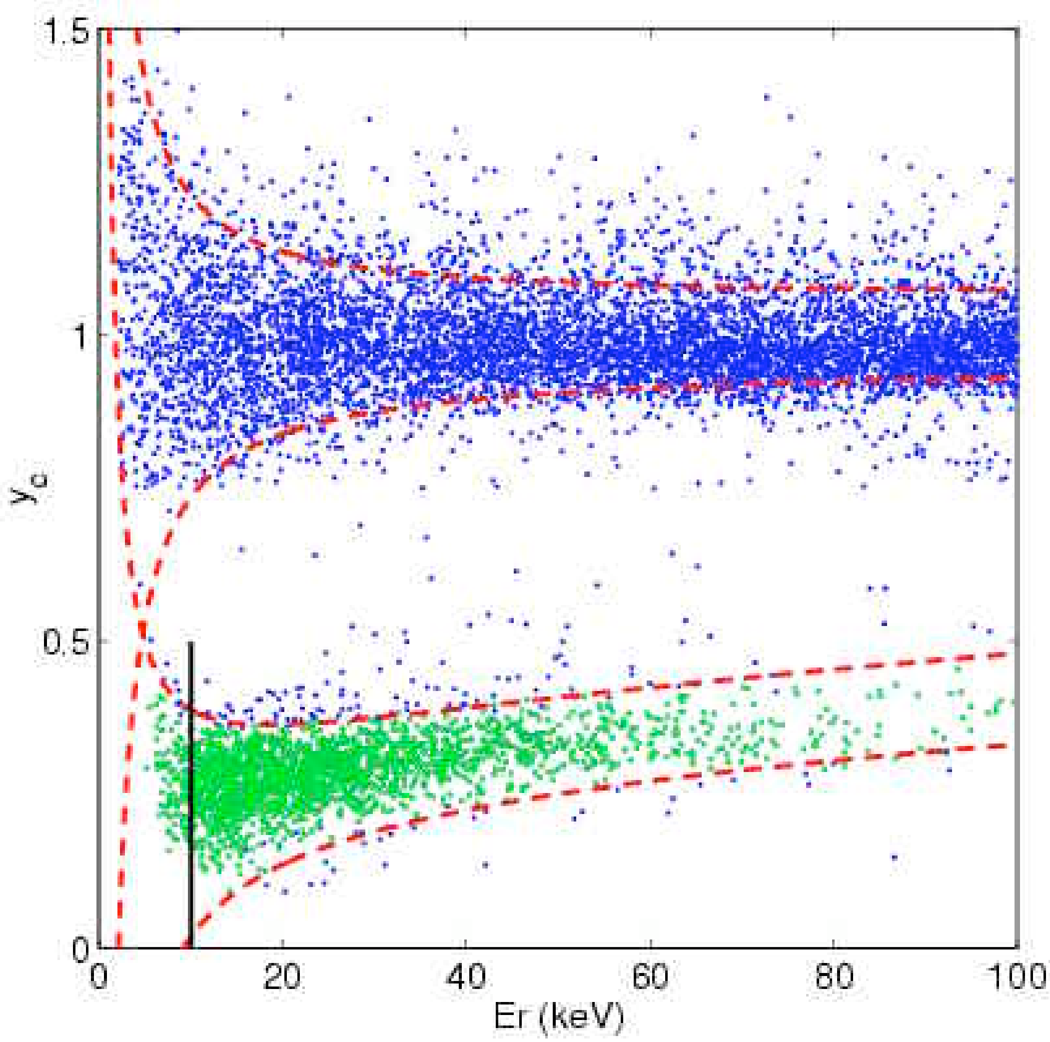


Run 118 (1T) & Run 119 (2T) in Soudan



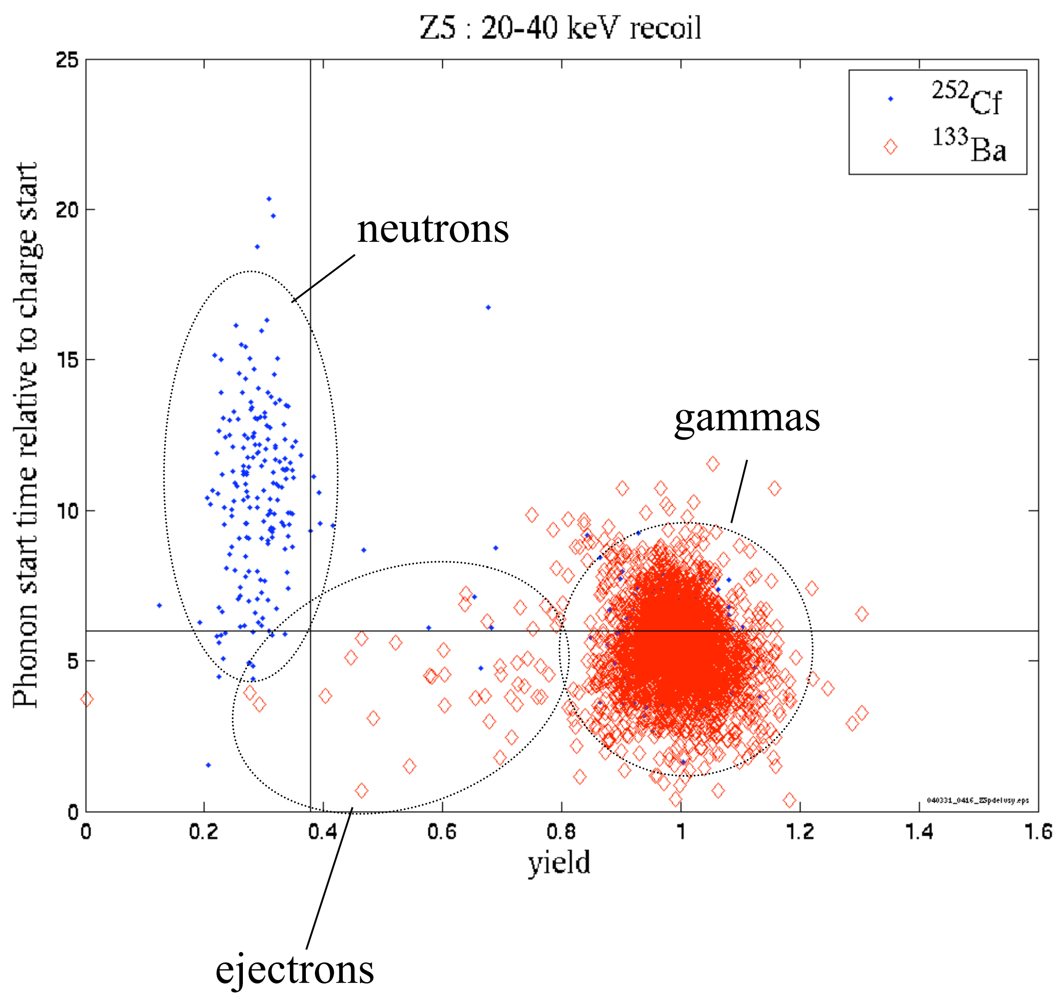
^{252}Cf Neutron & Gamma calibration data

- Upper red dashed line are +/- 2 э gamma band
- Lower red dashed line are +/- 2 э nuclear recoil band
- Separate high statistics calibrations with ^{133}Ba gamma source
- Determined with calibration data as was the analysis threshold energy



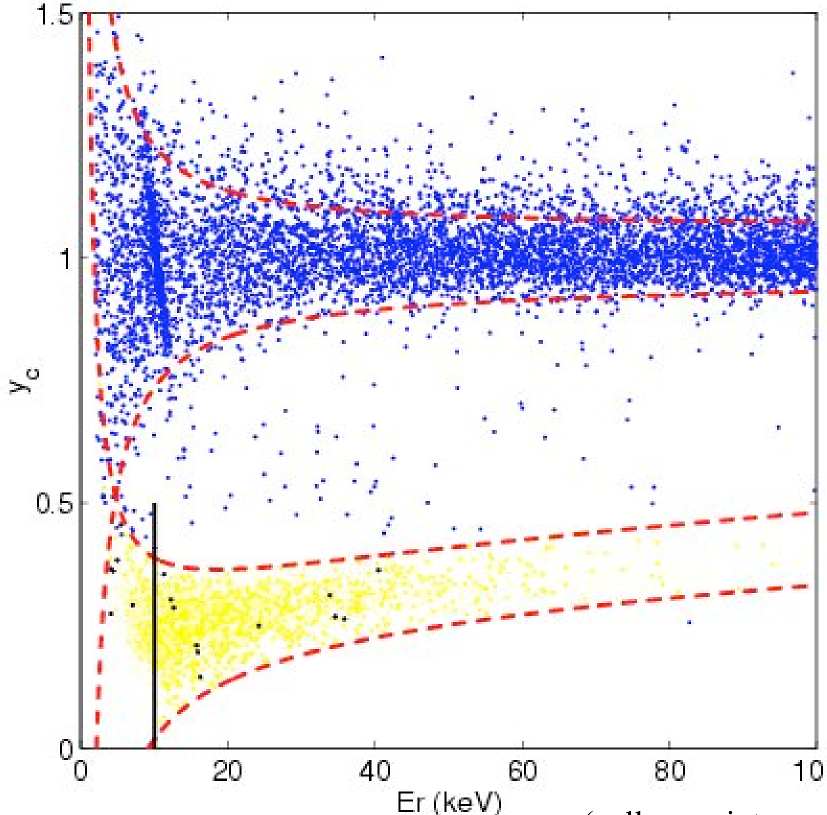
^{133}Ba gamma & ^{252}Cf neutron calibrations

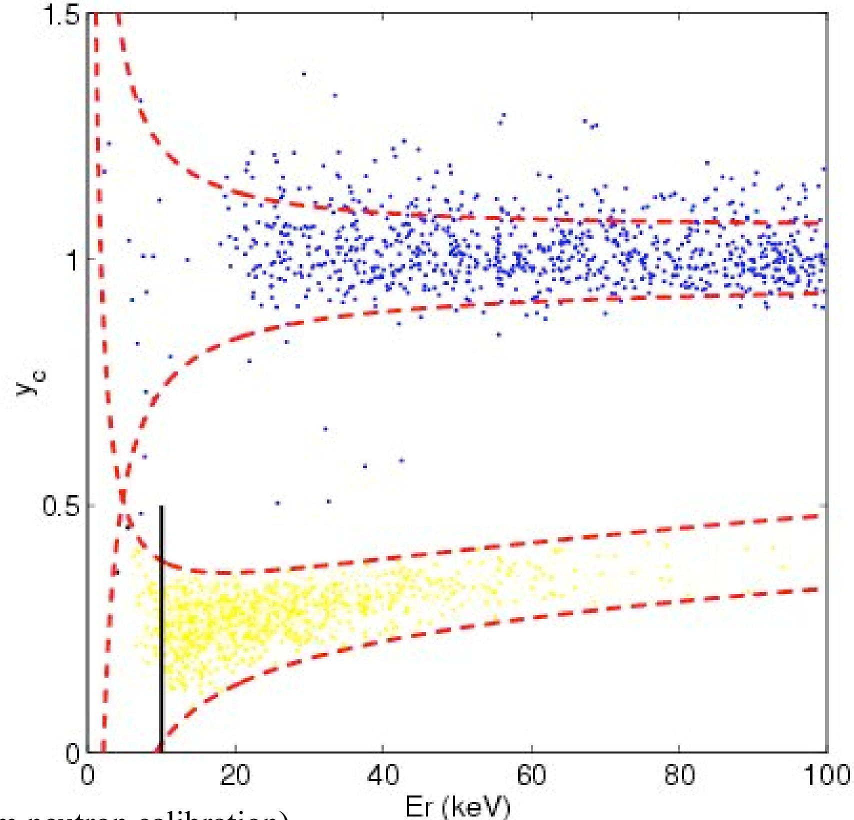
- Use phonon risetime and charge to phonon delay for discrimination of surface electrons "betas"
- Cuts and analysis thresholds determined entirely from calibration data with WIMP search data blinded until after the cuts and thresholds were set.



WIMP search data with Ge detectors

- In 92 days between October 11, 2003 and January 11, 2004, we collected 52.6 live days - a net exposure of 22 kg-d after cuts
- Below data are shown before (left) and after (right) timing cuts

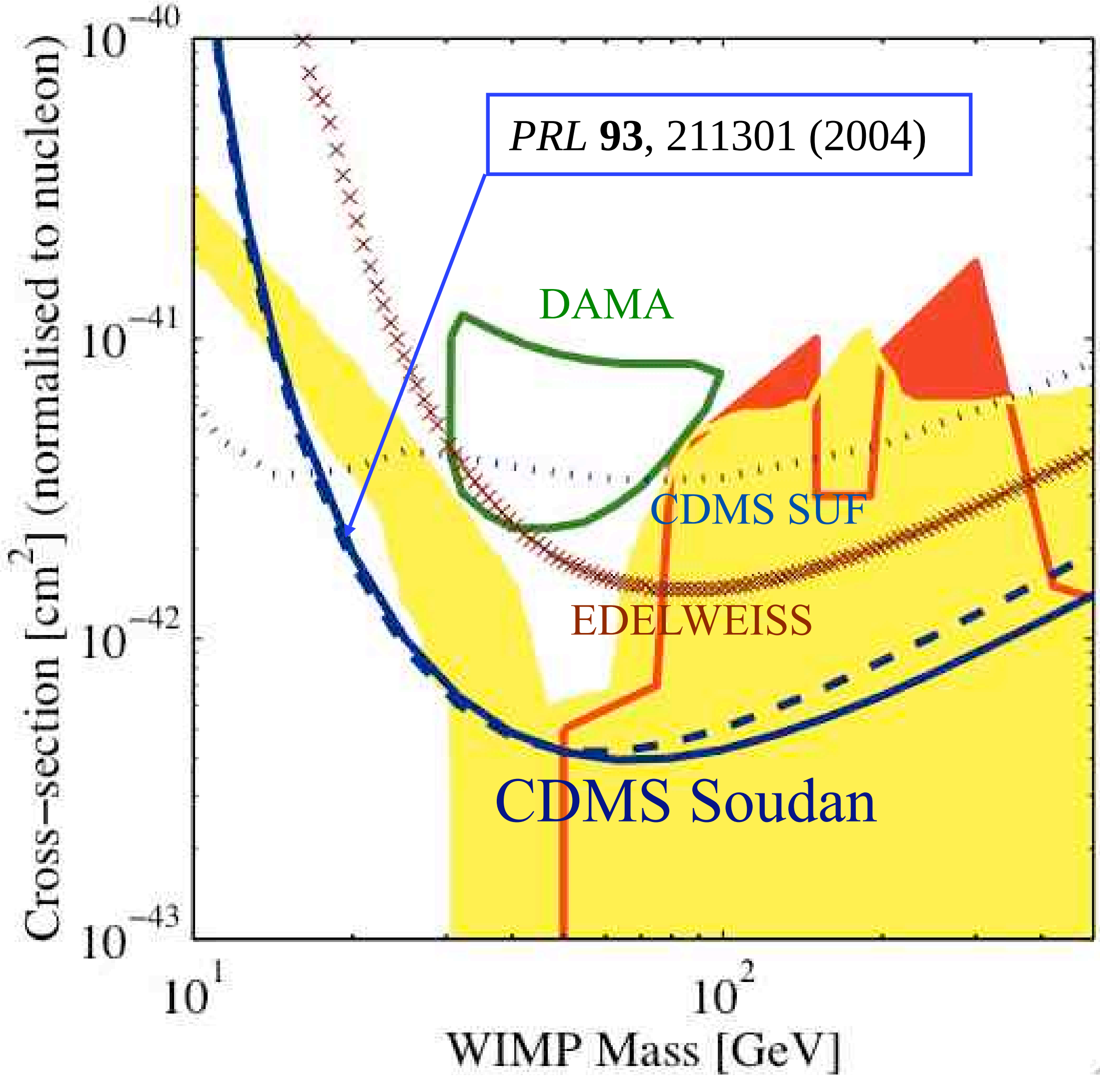




(yellow points are from neutron calibration)

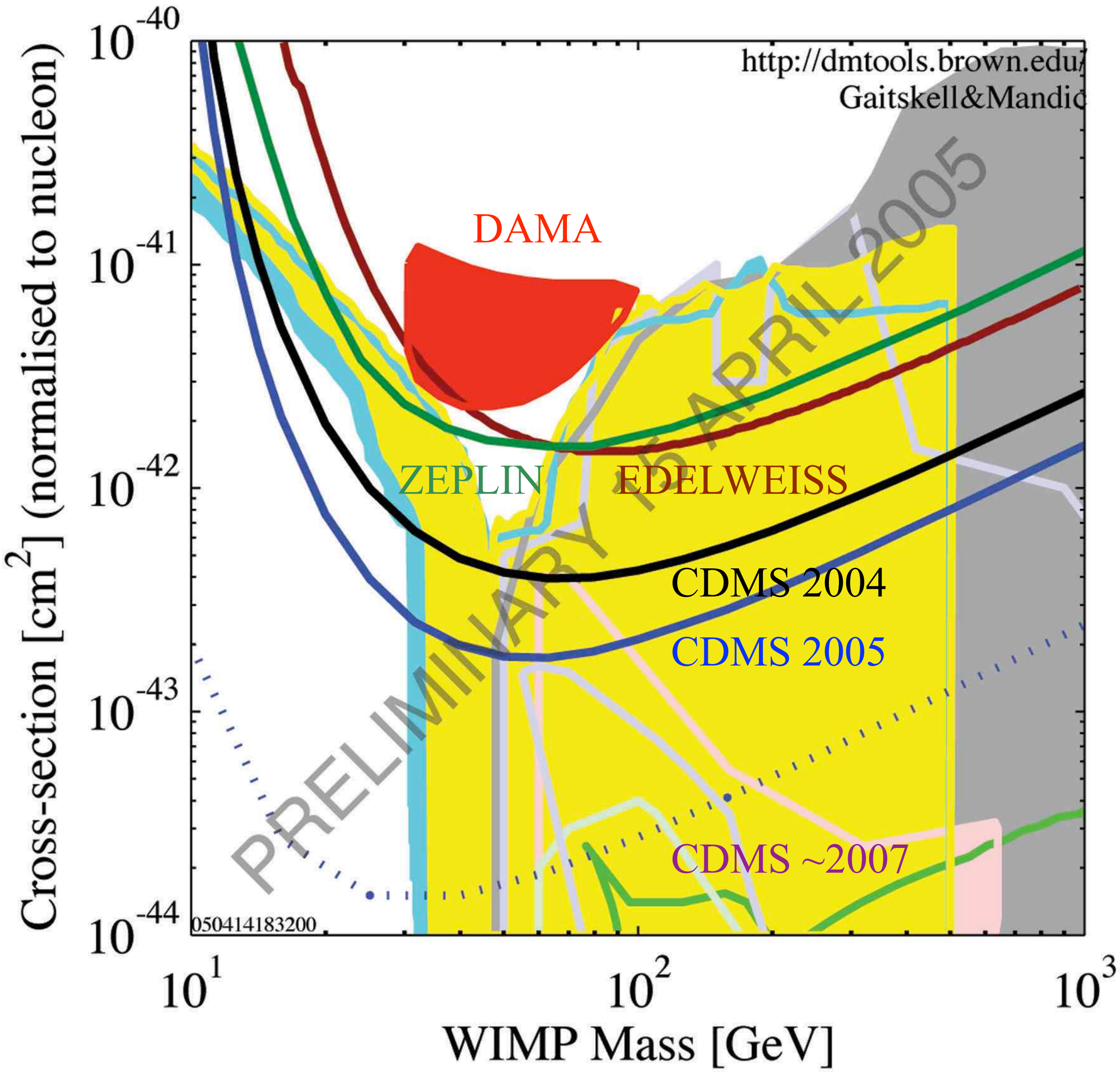
New CDMS limit from Soudan Lab

- Exposure after cuts of 52.6 kg-d raw exposure with Ge ≈ 20 kg-days for 60 GeV/c^2 WIMP
- NO EVENTS in nuclear recoil band (one leakage event second analysis)
- Expect 0.7 +/- 0.35 expected leakage betas
- Expect 0.05 unvetoed neutrons (1.9 muon coincident neutron)
- New limit ~x4 better than EDELWEISS at a WIMP mass of 60 GeV/c^2

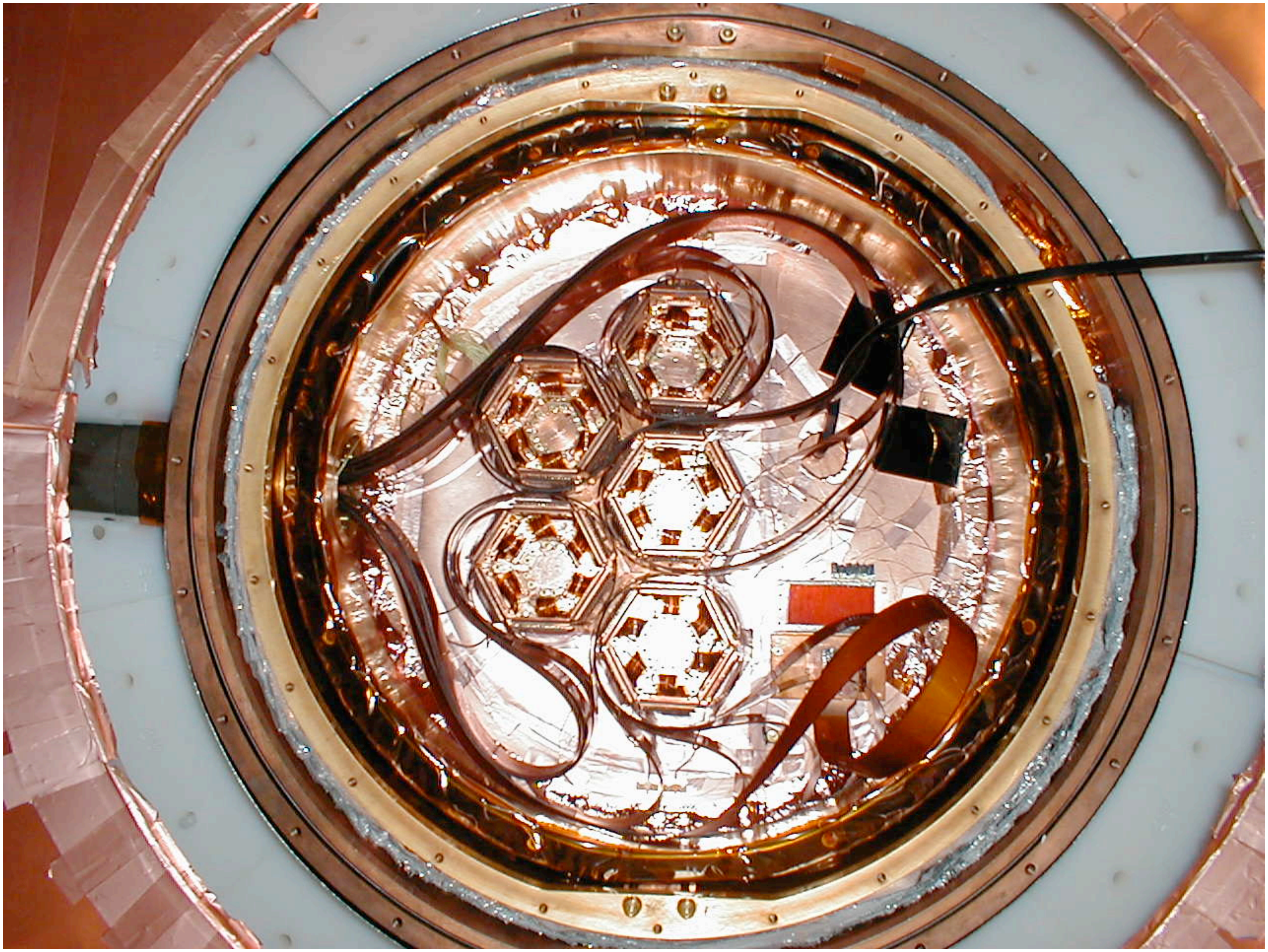


CDMS-II Reach with five Towers

- We have begun to explore MSSM cross section range
- DAMA largely ruled out for spin independent scalar interactions (see Gelmini & Gondolo hep-ph/0405278)
- Light mass region suggested by Bottino (hep-ph/0307303) largely ruled out
- Another factor of 3-5 improvement at Soudan past CDMS-II (neutrons)
- THEN MUST GO DEEPER - exploring SNOLab in Canada

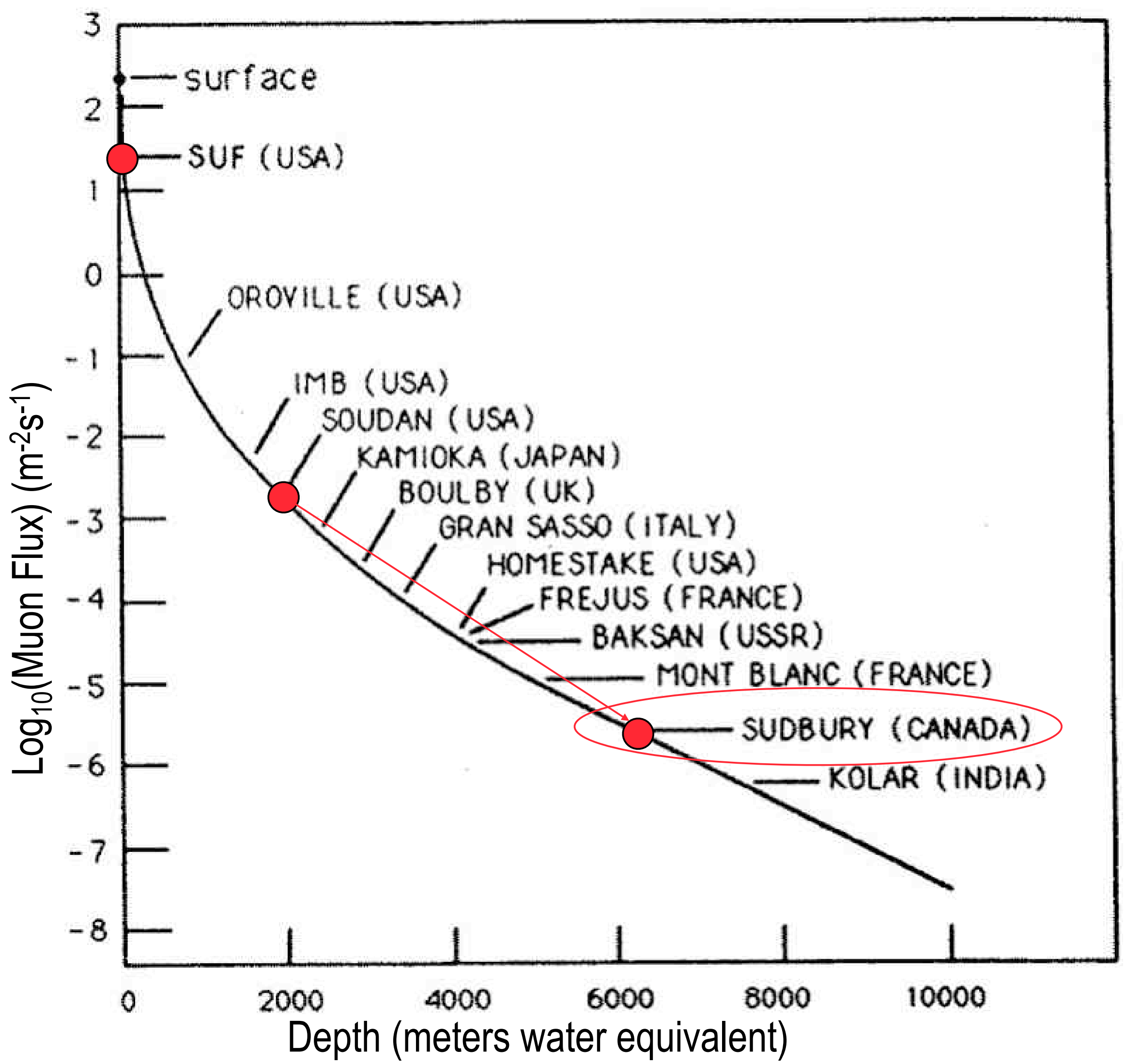


About to Operate Five Towers in Soudan



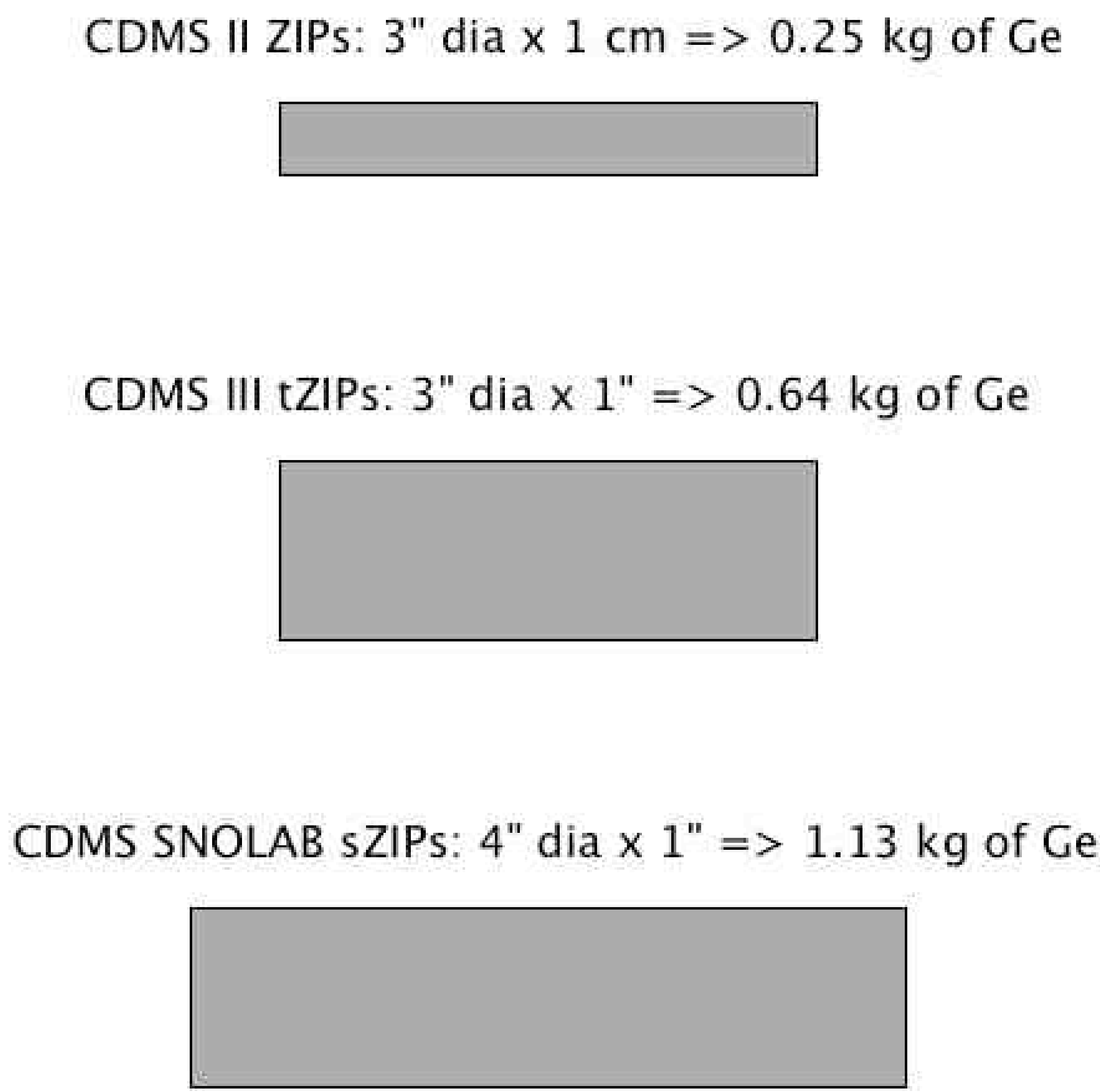
Propose to operate at SNOLab (6060 mwe)

- At SUF
  - 17 mwe
  - 0.5 n/d/kg
- At Soudan
  - 2090 mwe
  - 0.8 n/y/kg
- At SNOLab
  - 6060 mwe
  - 1 n/y/ton



Detector development

- Existing ZIPs
  3" dia x 1 cm thick
- Thicker ZIPs
  3" dia x 1" thick
  (base detector)
- Explore larger
  ZIPs to 4" dia and
  up to 4 cm thick



How to build a 1000 kg experiment in stages

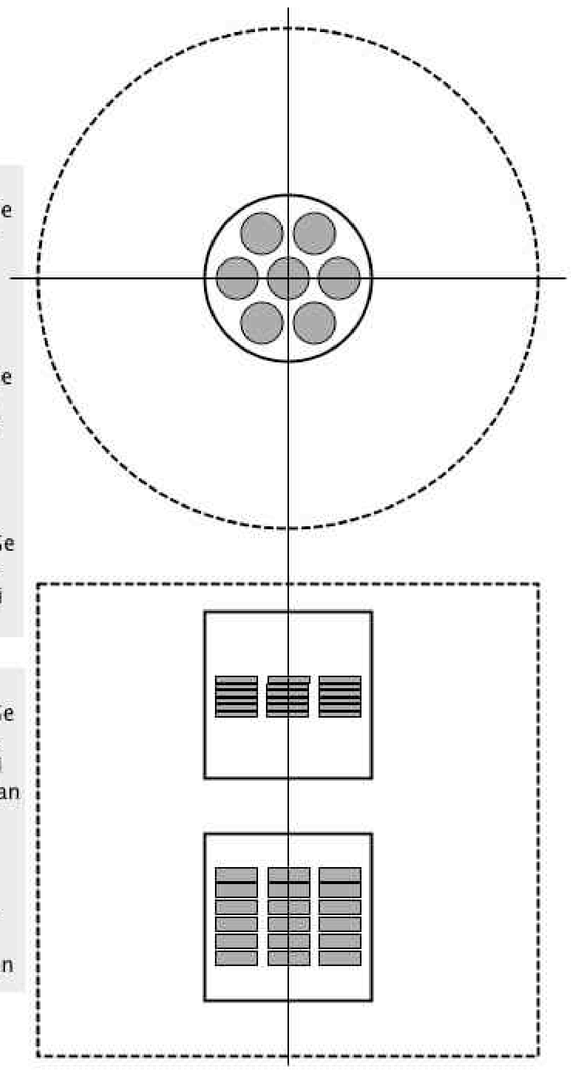
CDMS II – Phase A:
3"x1 cm => .25 kg Ge
1 x 6 Det Towers =>
1 kg Ge + 0.2 kg Si
SUF -> Soudan

CDMS II – Phase B:
3"x1 cm => .25 kg Ge
2 x 6 Det Towers =>
1.5 kg Ge + 0.6 kg Si
Soudan

CDMS II – Phase C:
3"x1 cm => .25 kg Ge
5 x 6 Det Towers =>
4.5 kg Ge + 1.2 kg Si
Soudan

CDMS III – Phase A:
3"x1 cm => .25 kg Ge
5 x 6 Det Towers =>
4.5 kg Ge + 1.2 kg Si
x3 exposure at Soudan

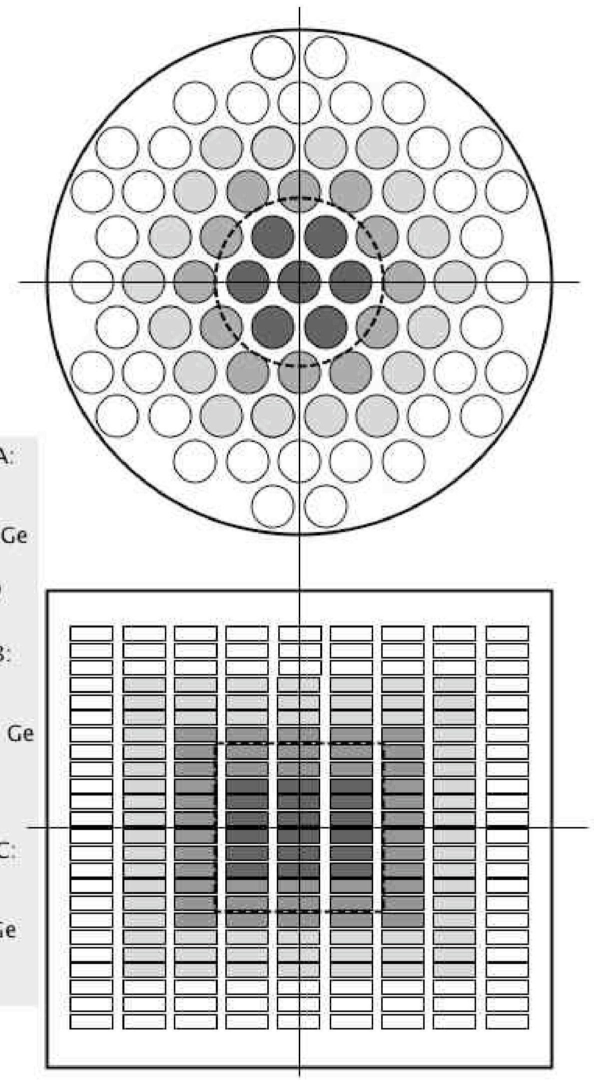
CDMS III – Phase B:
3"x1" => .64 kg Ge
2 x 6 Det Towers =>
up to 7.6 kg Ge
x10 less n's at Soudan



CDMS SNOLAB – Phase A:
3"x1" => 0.64 kg Ge
7 x 6-Det Towers =
42 Dets =>to 26.7 kg Ge
Soudan -> SNOLAB
SUF testing (2 batches)

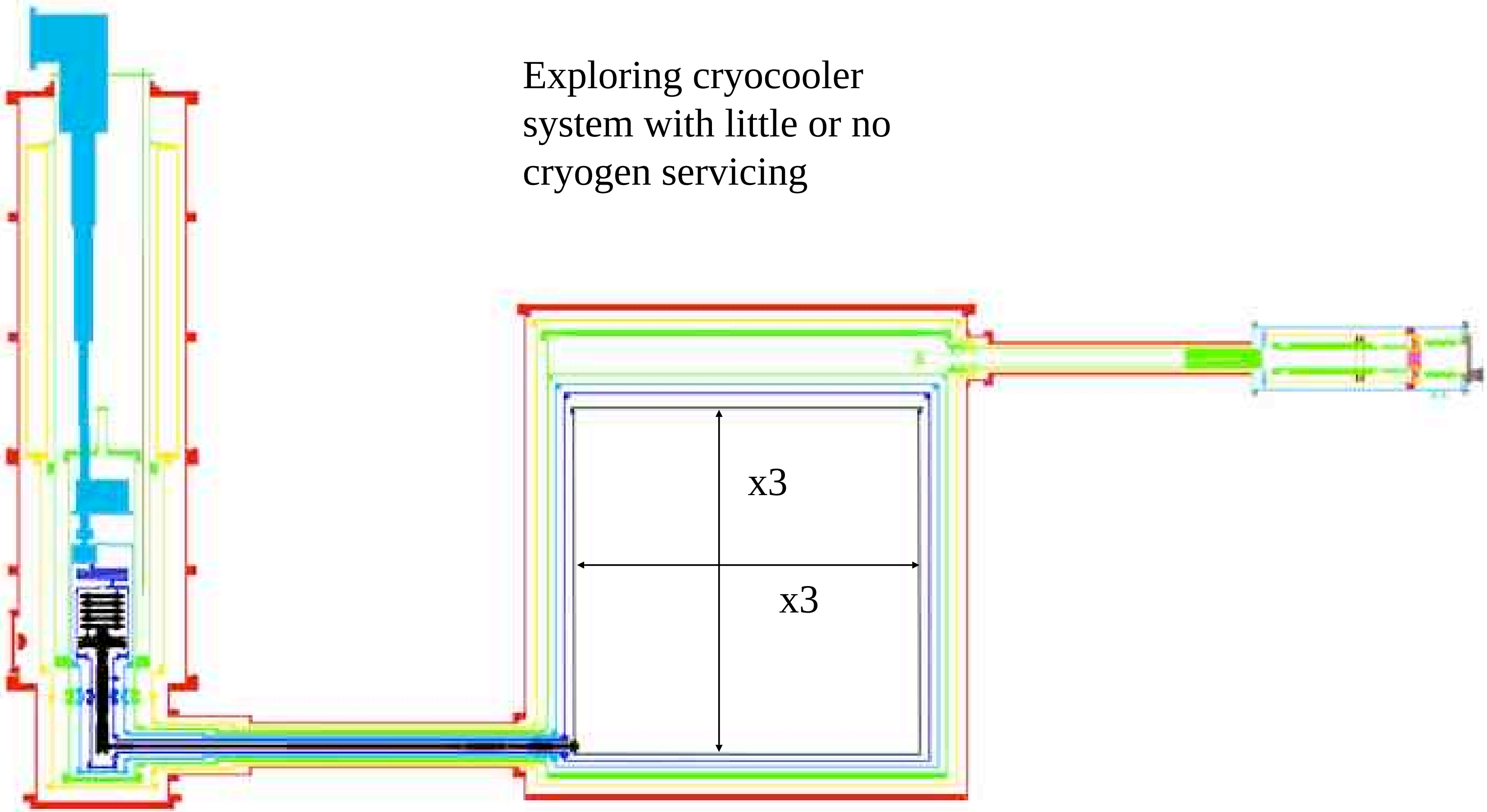
CDMS SNOLAB – Phase B:
3"x1" => 0.64 kg Ge
19 x 12-Det Towers =
228 Dets =>to 145 kg Ge
Soudan/SUF testing
(6 batches)

CDMS SNOLAB – Phase C:
3"x1" => 0.64 kg Ge
73 x 24 Det Towers =
1752 =>to 1,113 kg Ge
Soudan/SUF testing
(45 batches)

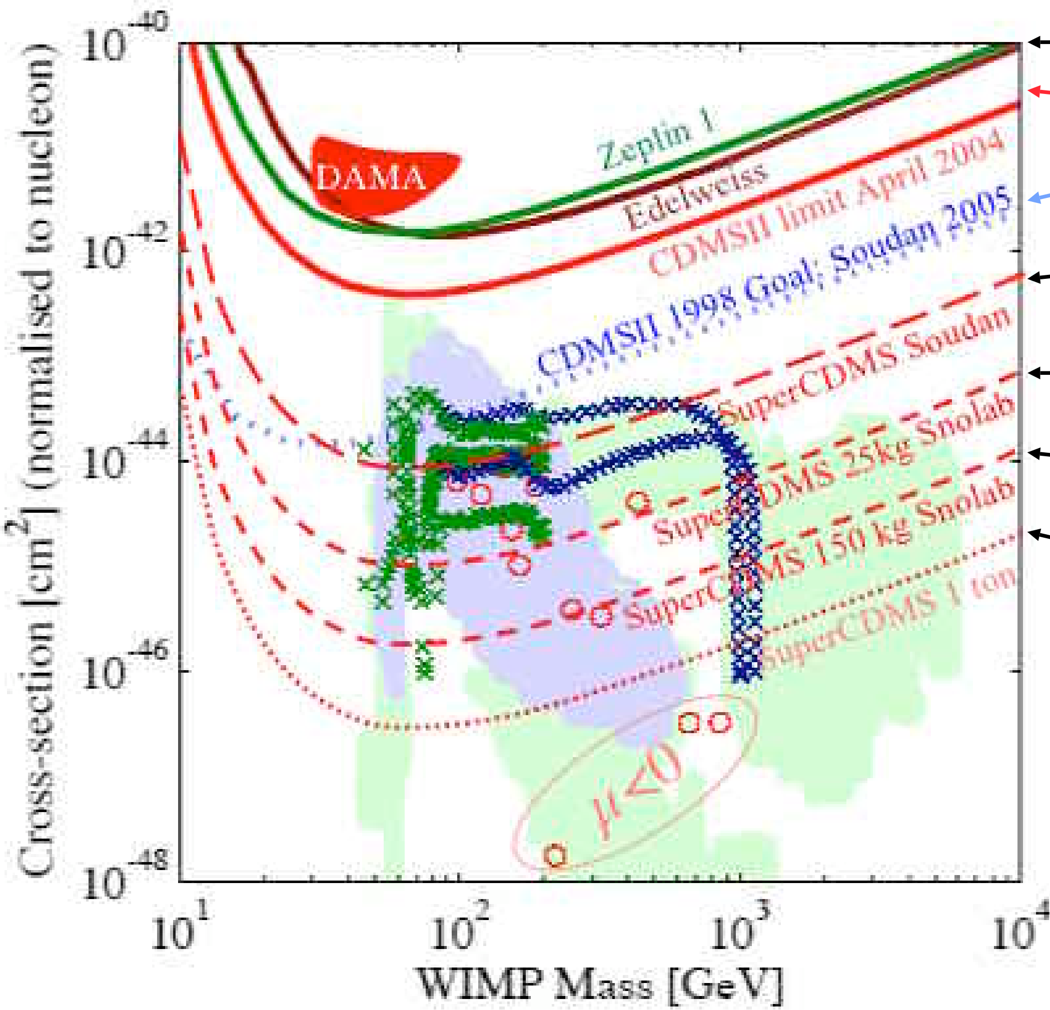


Schematic of new 'SNObox'

Exploring cryocooler system with little or no cryogen servicing



Summary and bold future vision



Limit at SUF 2002 (during CDMS II)

World-best limit today

CDMS II goal 2006

Development Project
5 kg of Ge 2008

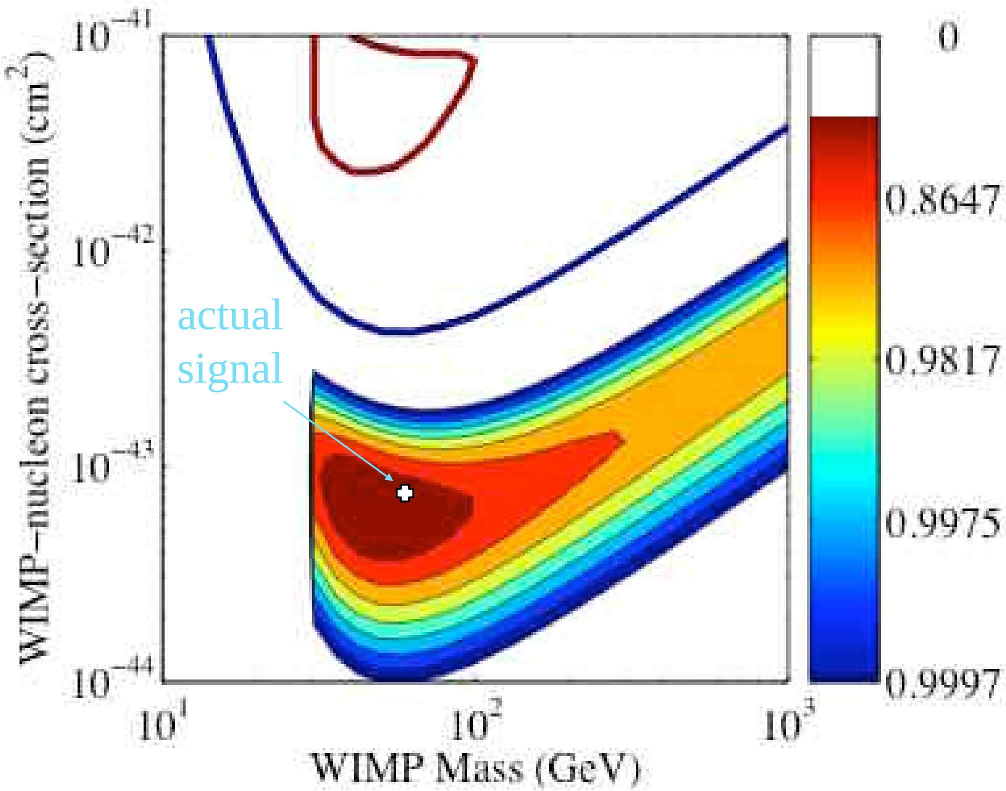
SuperCDMS Phase A
25 kg of Ge 2011

SuperCDMS Phase B
150 kg of Ge 2014

SuperCDMS Phase C
1000 kg of Ge

What do we learn if we see a signal?

- Our recent 90% C. L. corresponds to < 1 evt per 8 kg-d for Ge
- Suppose we see 8 events at the rate of 1 evt per 50 kg-d of Ge
- Then mass & cross section determined as shown and SI vs SD determined from different targets
- Suggest properties to look for at LHC and future LC



A convincing signal would motivate large TPC such as DRIFT for velocity distribution

If SUSY seen first at LHC would still want to determine if LSP is the dark matter,
SO NEED TO PUSH DIRECT DETECTION EITHER WAY

Conclusion

- Compelling scientific case for dark matter in the form of WIMPs and specifically the neutralino or LSP
- CDMS-II leads the field by a factor of ~~four~~ ten with recent results. Another factor of ~~twenty~~ ten increase in sensitivity expected over next year.
- Proposed SuperCDMS Development Project continues to run CDMS-II Towers, develops larger ZIP detectors, and operates one SNOLAB Tower at Soudan in 2008
- Start SNOLAB installation in 2007 so that detectors can be operated starting in 2009
- Very exciting time as we probe most interesting region and Fermilab can take lead role in potential discovery !