“Physics in Collision”

SUSY Dark Matter, Cryogenic Dark Matter Search, DAMA & Future of Direct Searches 000701

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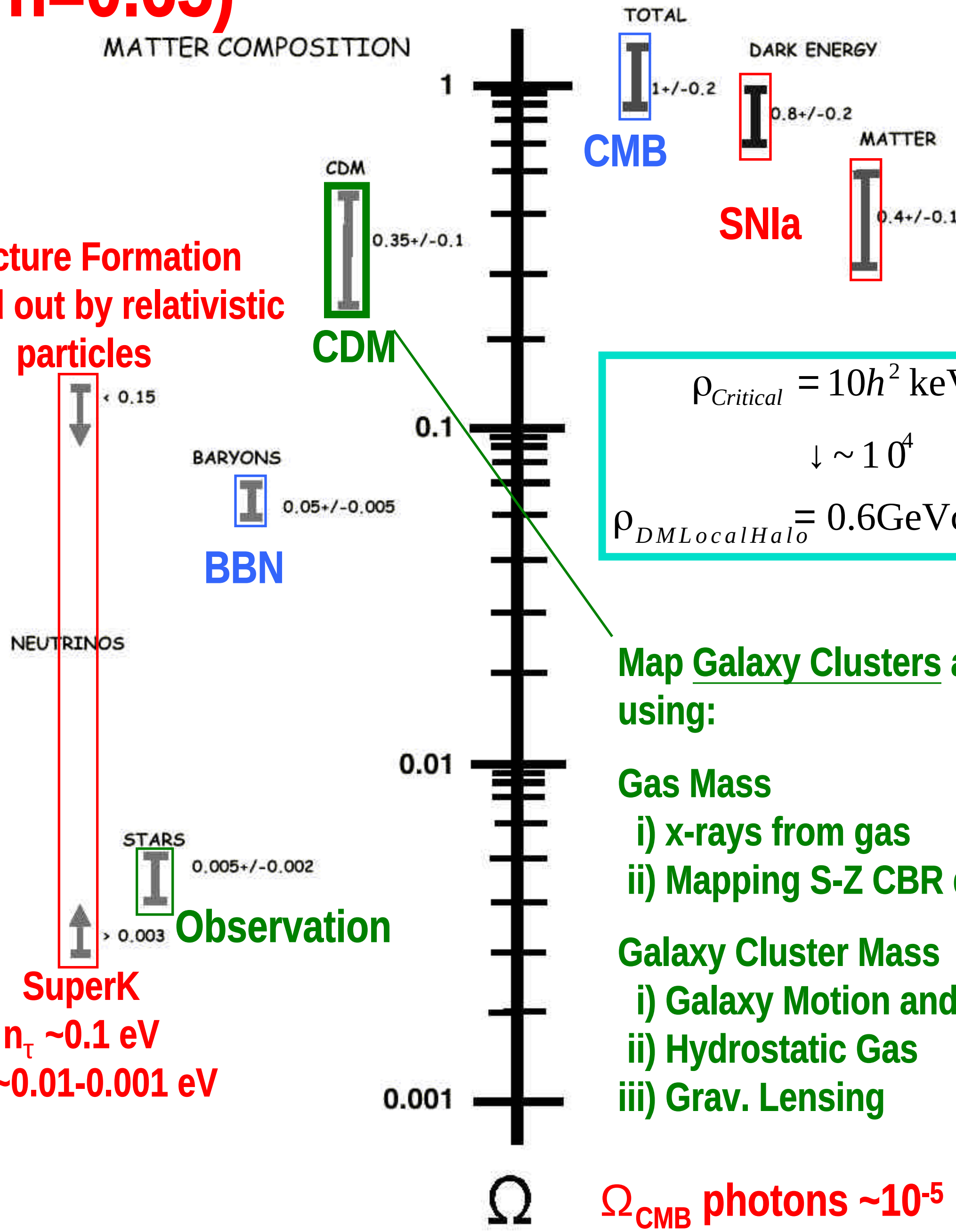
source at http://cdms.berkeley.edu/gaitskell/

Outline

- **Interplay of Cosmology and Particle Physics**
  - 3 Dark Matter Problems
  - SUSY Particle Dark Matter's possible place in the Universe
- **Cryogenic Dark Matter Search - Results from CDMS-I**
  - Explain a little of the philosophy & techniques behind this experiment
  - Results from CDMS I & Incompatibility with DAMA positive result
- **Future of SUSY Dark Matter Experiments**
  - SUSY Reach
    - Predictions for LSP σ on quarks - lower limit apparent for calculations using mSUGRA Framework & Naturalness
  - Future of Experiments

Ω (assumes h=0.65)



Structure Formation washed out by relativistic particles

SuperK
n_τ ~0.1 eV
n_μ ~0.01-0.001 eV

$$\rho_{Critical} = 10h^2\ \mathrm{keV cm}^{-3}$$
$$\downarrow \sim 10^4$$
$$\rho_{DMLocalHalo} = 0.6\ \mathrm{GeV cm}^{-3}\ \text{(factor 2 uncertainty)}$$

Success of CDM Cold Dark Matter Models in relating

Homogeneity of CMB Cosmic Microwave Background

with development of LSS Large Scale Structure

Map Galaxy Clusters at few Mpc scale using:

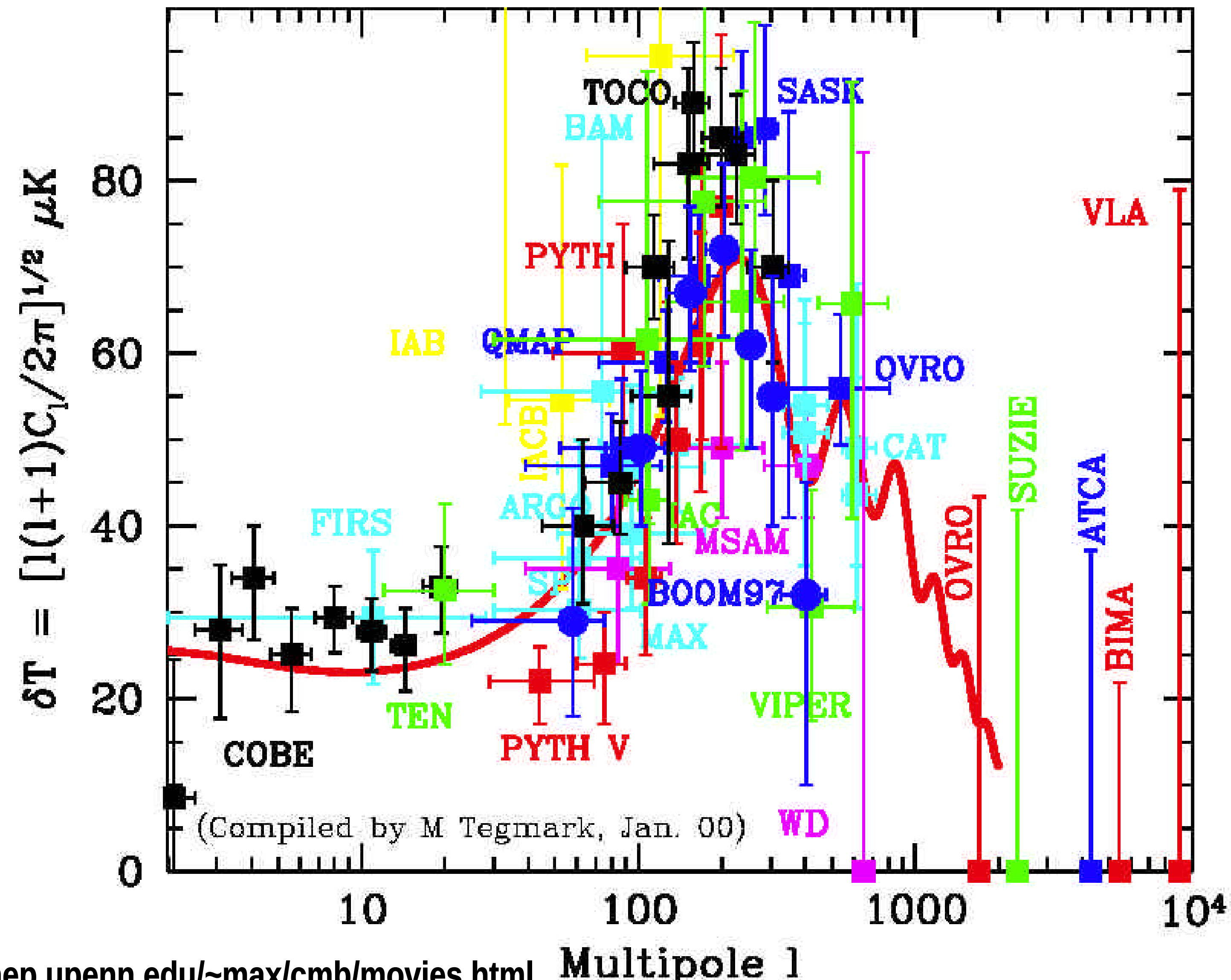
Gas Mass
i) x-rays from gas
ii) Mapping S-Z CBR decrement

Galaxy Cluster Mass
i) Galaxy Motion and Virial Th.
ii) Hydrostatic Gas
iii) Grav. Lensing

Ω_{CMB} photons ~10^{-5}

Mike Turner, Chicago

CMB Fluctuations - Primary Peak Position



http://www.hep.upenn.edu/~max/cmb/movies.html

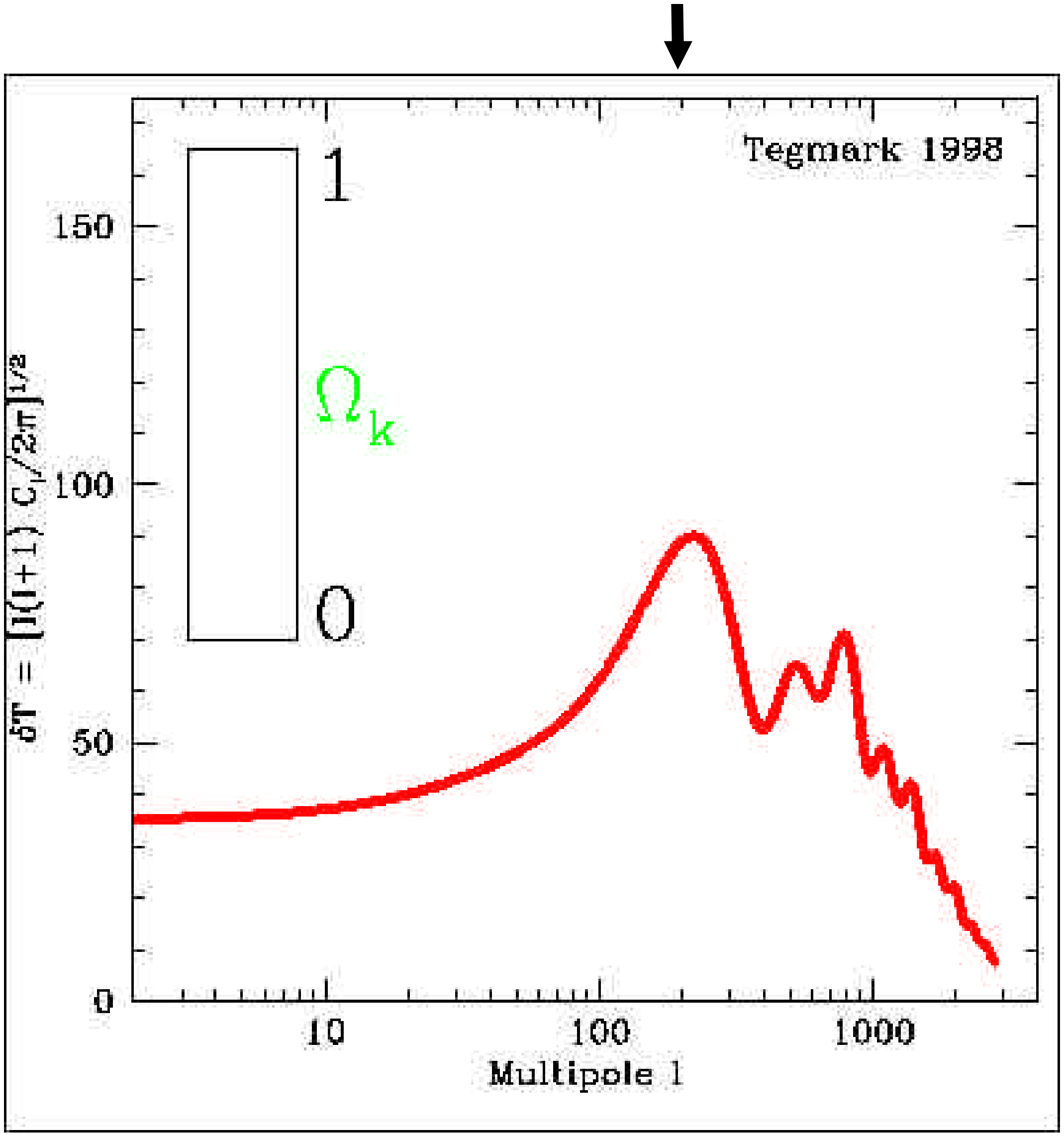
CMB Fluctuations - Primary Peak Position

$\Omega_m + \Omega_\Lambda = 0$ **OPEN Geometry**

$\Omega_m + \Omega_\Lambda = 1 - \Omega_k$

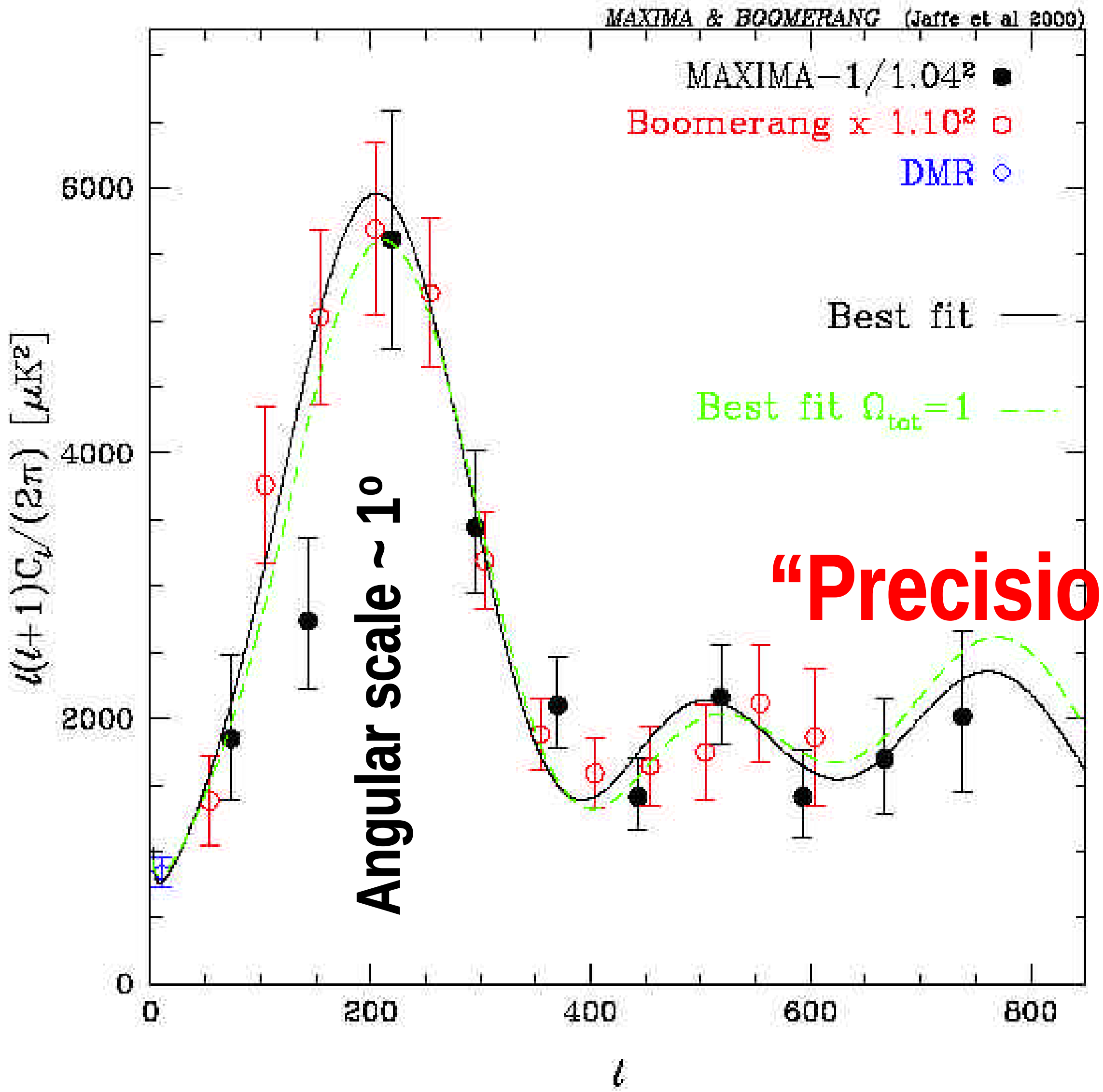
$\Omega_m + \Omega_\Lambda = 1$ **FLAT Geometry**

- **Curvature was irrelevant at z~1000**
- **However, apparent angular scale (θ~200 / l) of fluctuations (original a distance) when observed at z=0 is distorted by space geometry**
- **Positive Ω_k , negative curvature (saddle) so features subtend smaller angle θ**



http://www.hep.upenn.edu/~max/cmb/movies.html

Boomerang/Maxima (Balloon CMB Experiments)

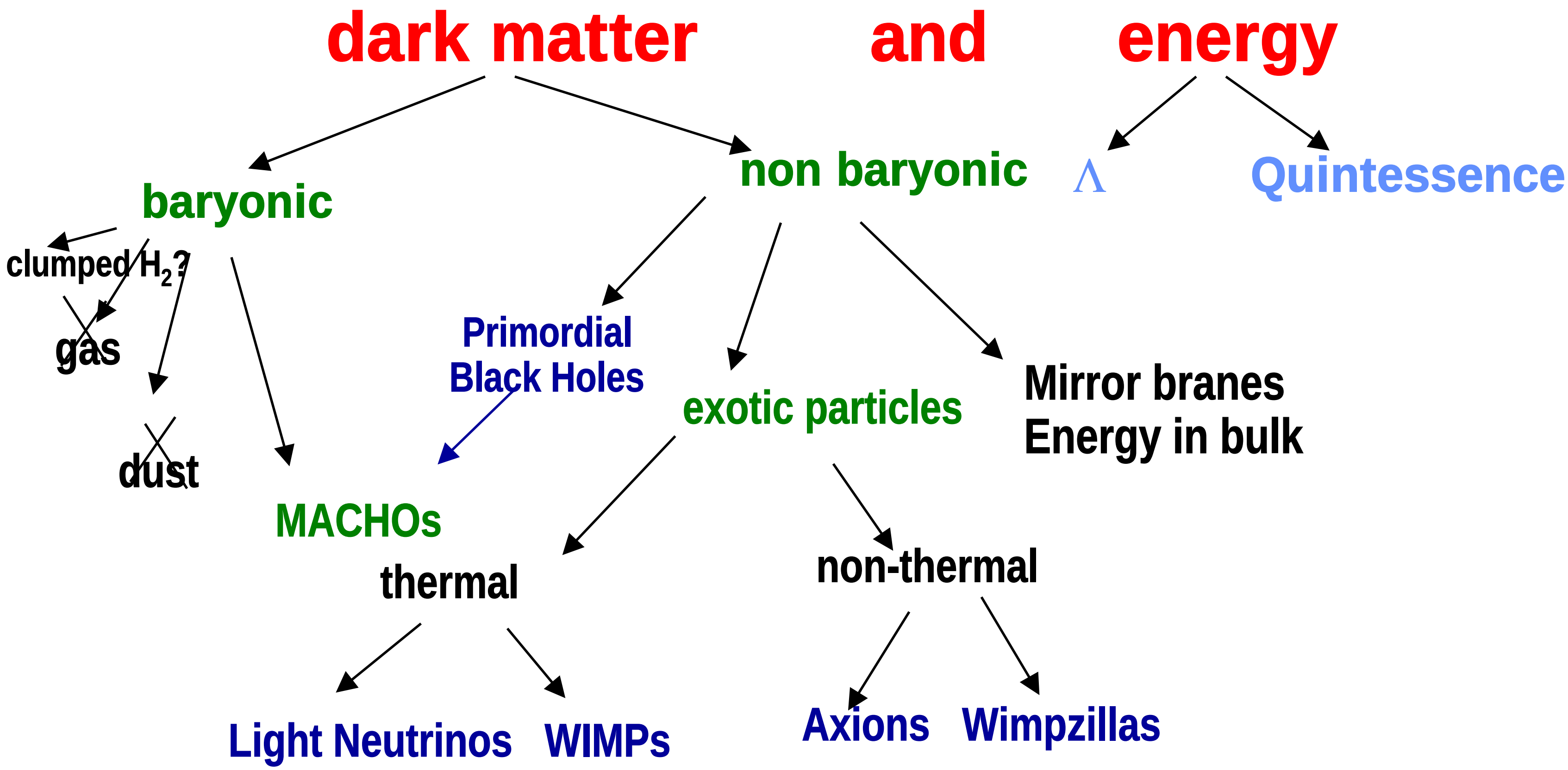


Andrew Jaffe, UCB

Combined results from Boomerang and Maxima (May 2000)

"Precision Cosmology"

The Dark Matter Problem



- Cosmology <--> Particle Physics
- Systematically map possibilities
  - Exclude most candidates
- Start with the candidates which have at least 2 motivations

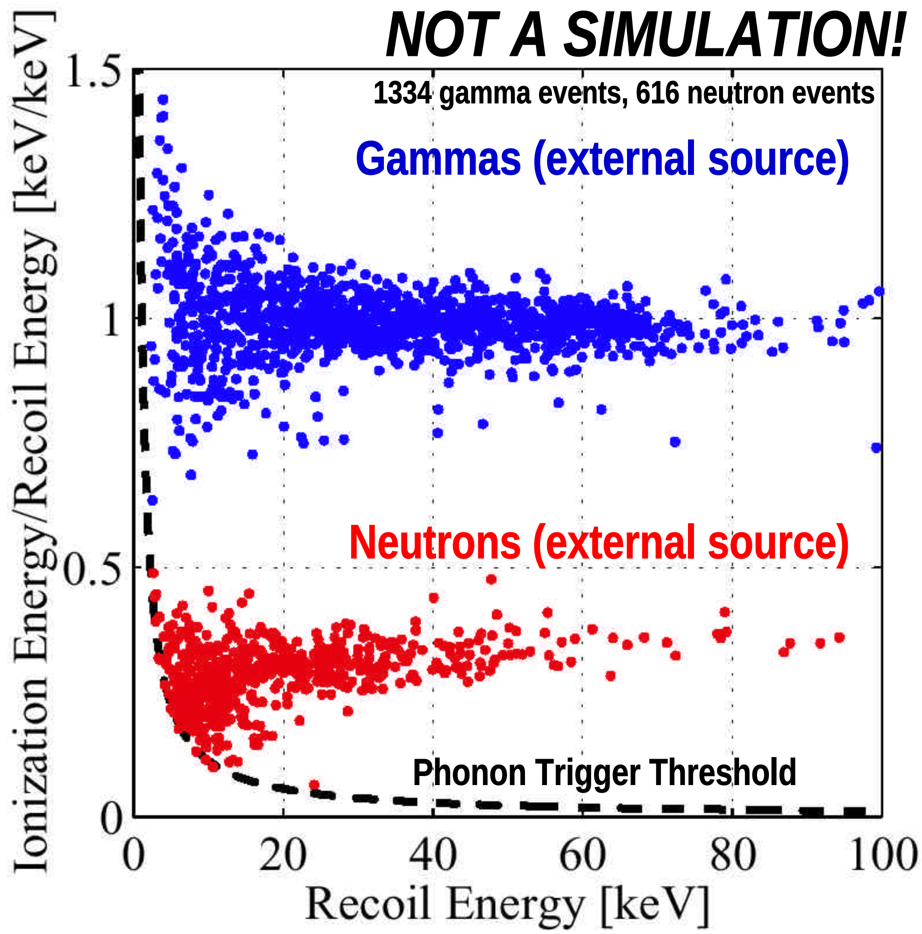
Nuclear Recoil Discrimination - Event by Event

- Nuclear recoils arise from
  - WIMPs
  - Neutrons

- Electron Recoils arise from
  - photons
  - electrons
  - alphas

  (Typical Background)

- Ionization yield
  - ionization/recoil energy strongly dependent on type of recoil
- Recoil energy
  - Phonons give full recoil energy



Overview

- **CDMS-I**
  - **This presentation will cover a full analysis of event data that was taken as part of Cryogenic Dark Matter Search experiment based at the Stanford Underground Facility(*)**
  - **1998 (2 months)**
    - **33 live days 100 g Si ZIP -> 1.6 kg-days after cuts**
    - **(4 nuclear recoil events observed)**
  - **1999 (12 months)**
    - **96 live days 4x165 g Ge BLIP -> 10.6 kg-days after cuts**
    - **(17 nuclear recoil events observed)**

(*) Used to be called Stanford Low Radioactivity Facility but the radiation safety paperwork became too onerous

CDMS Collaboration

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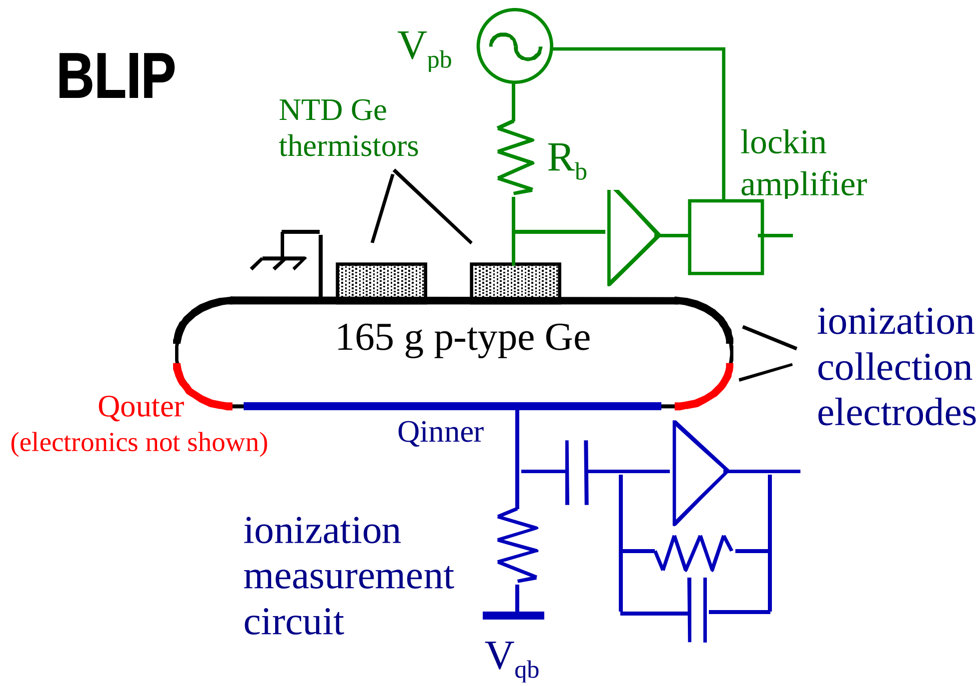
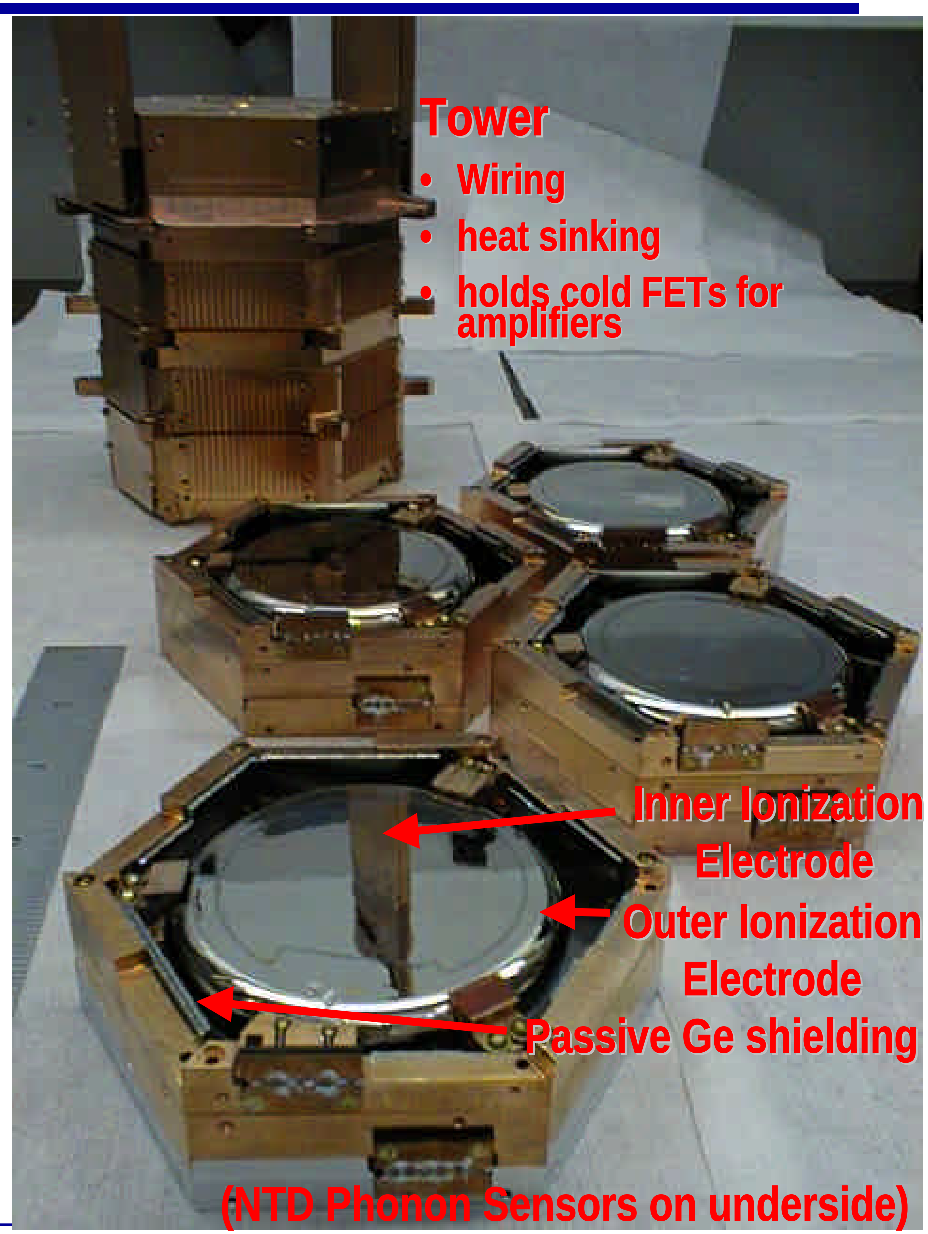
(Feb00 ALS)

Ge BLIP Ionization & Phonon Detectors

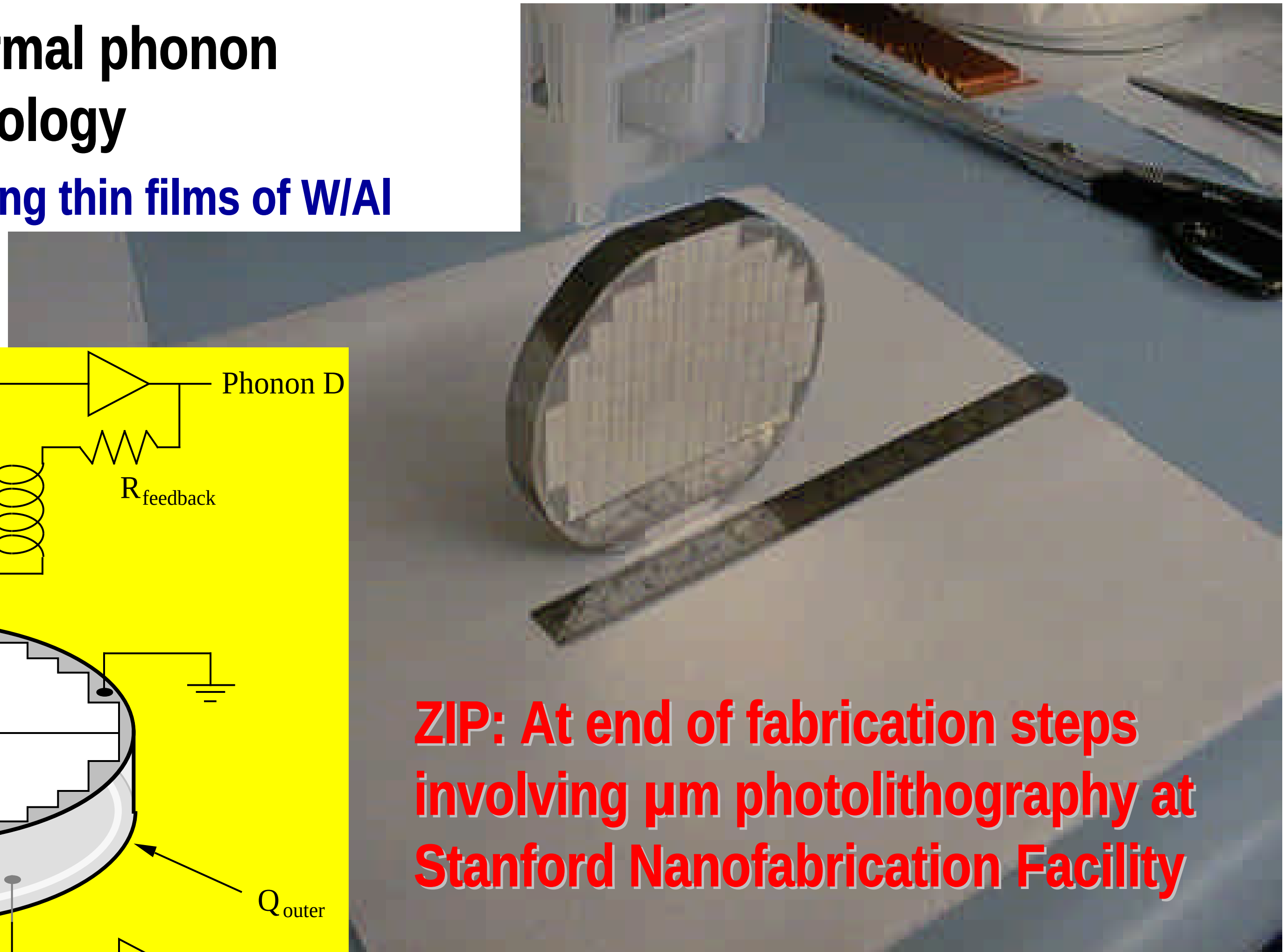


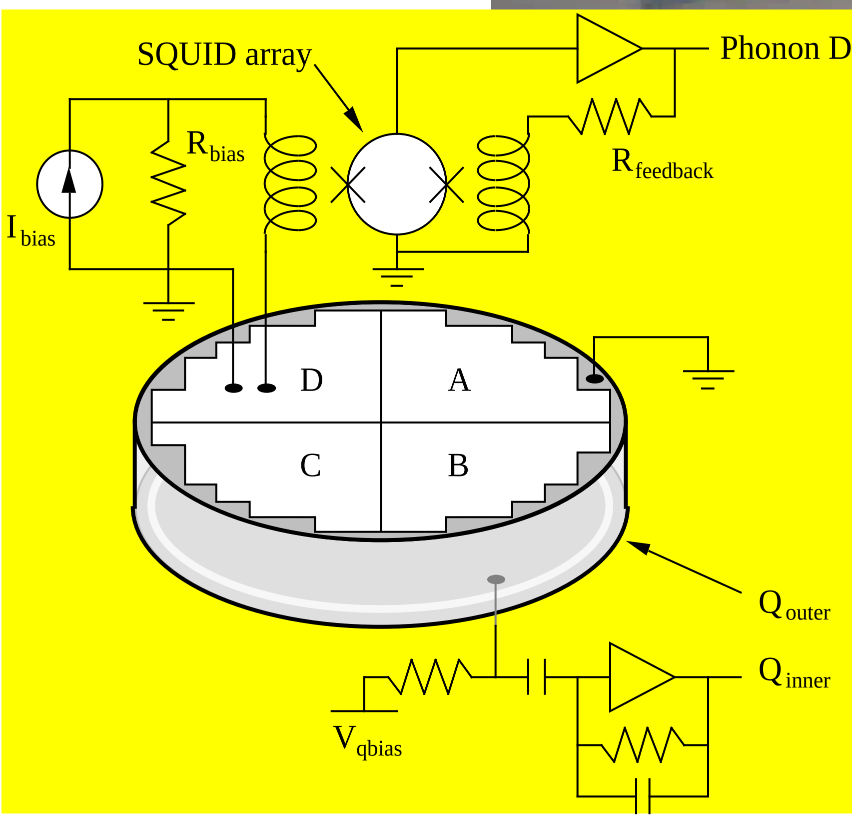
- **Four 165 g Ge detectors, for total mass of 0.66 kg during 1999 Run**
- **Calorimetric measurement of total energy**
- **ENERGY Resolution**
  - **σ = Ionisation 220 eV, Phonons 250 eV**



Si ZIP Ionization & Phonon Detectors

- **Advanced athermal phonon detection technology**
  - **Superconducting thin films of W/Al**





ZIP: At end of fabrication steps involving µm photolithography at Stanford Nanofabrication Facility

Detector Environment

Stanford Underground Facility

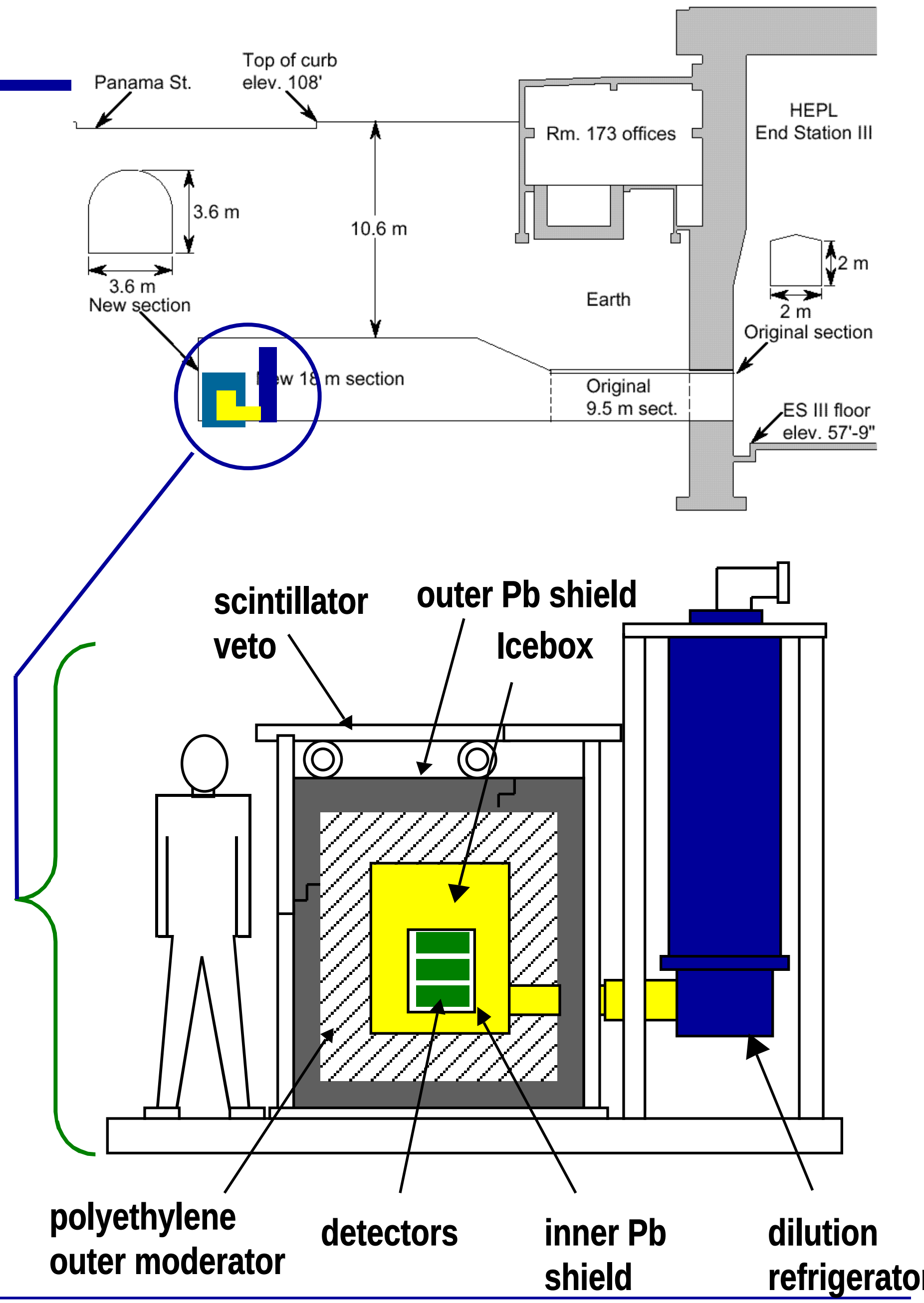
- 17 mwe of rock
- hadronic component down by >1000
- muon flux down by ~5

Low-Background Environment

- 25 cm polyethylene reduces muon-induced neutron flux from rock and lead by factor >100
- 15 cm Pb reduces photon flux by factor >1000
- radiopure cold volume (10 kg)
- additional internal (ancient) lead shielding

Active Scintillator Muon Veto

- muon veto >99.9% efficient
- reject ~22 “internal” neutrons/ day produced by muons within shield

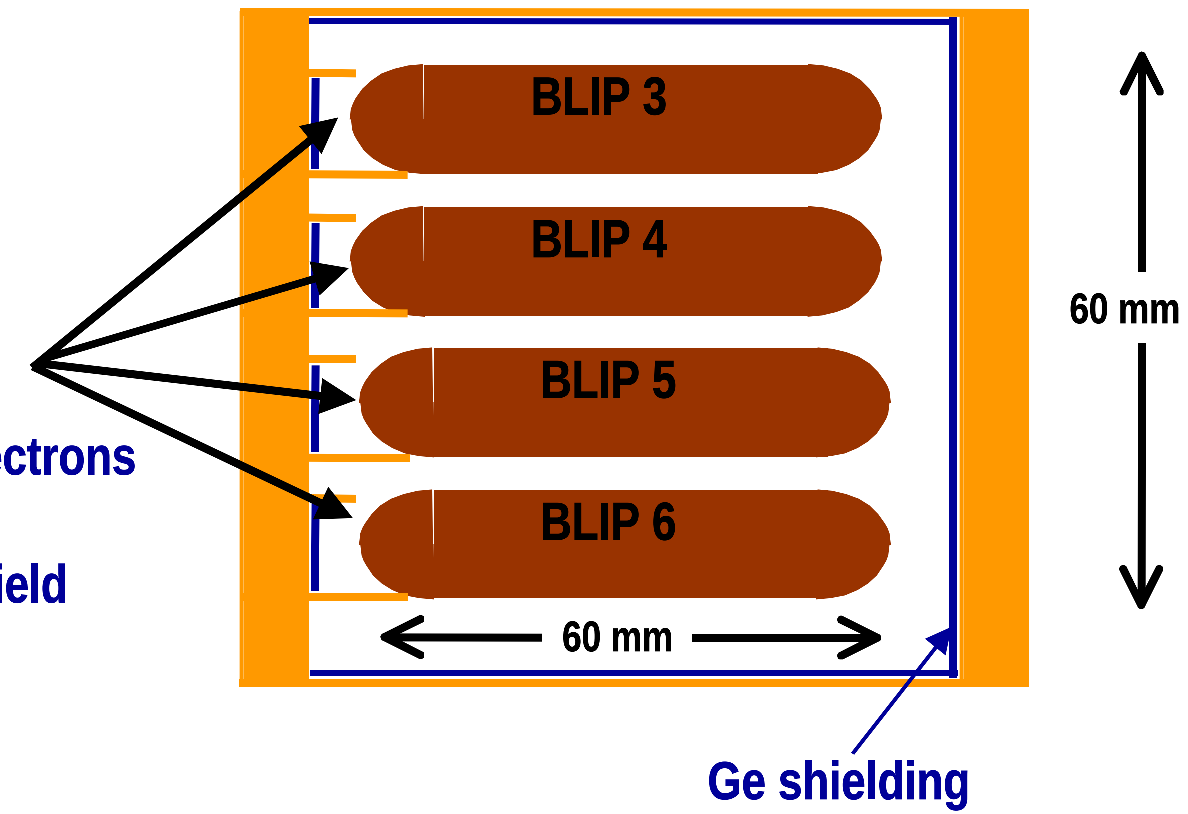


4 x BLIP Tower Schematic (1999 Run)

- 1999 Run (net 10.6 kg-days)
- Low-radioactivity Cu and Ge housing
- Self-shielding through close packing
  - Spacing 3 mm vertically

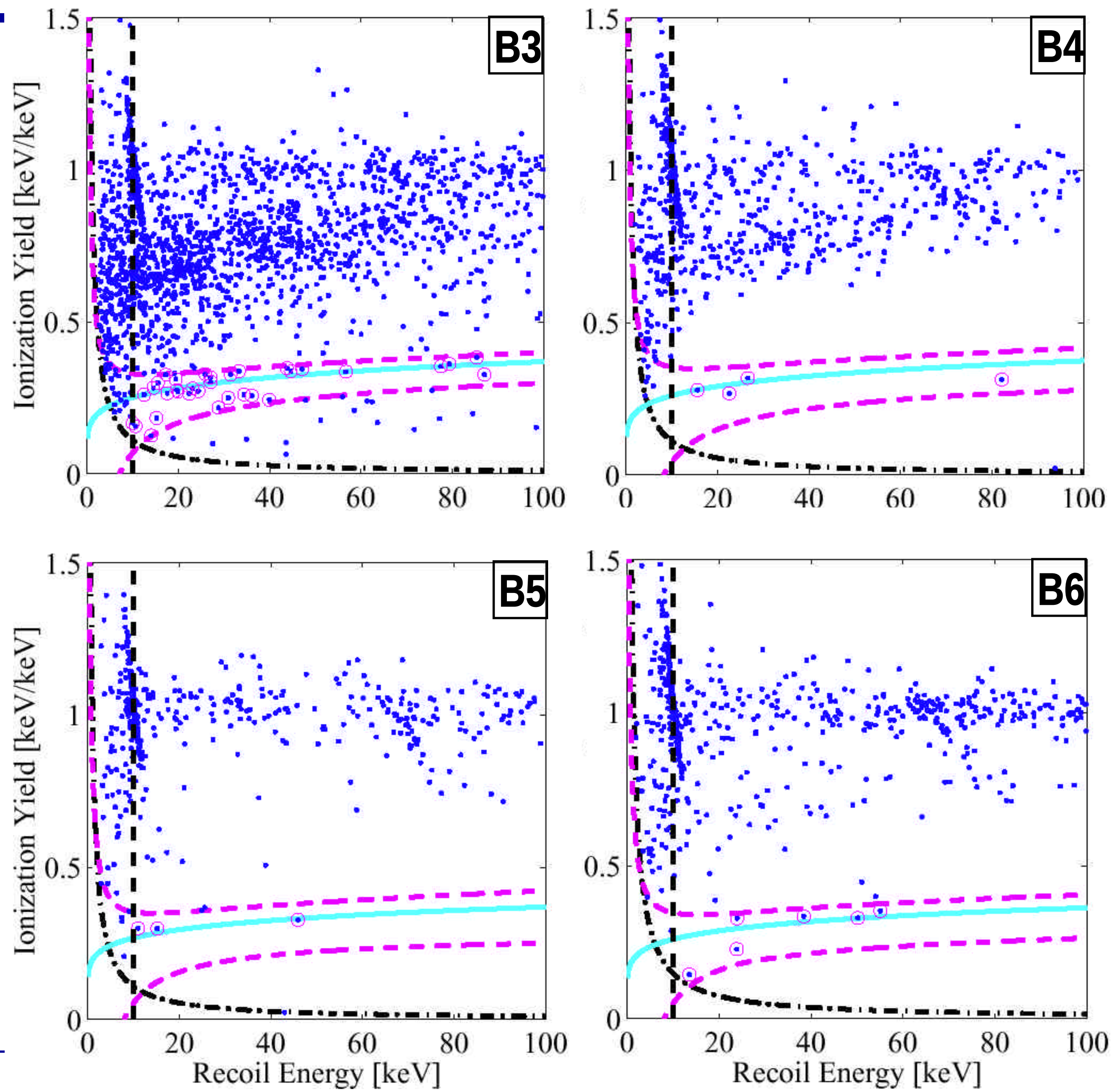
Outer Ionization Electrodes

- less shielded from electrons (surface events)
- imperfect ionization yield (electrode break)



Anticoincident Ionisation Energy/Recoil Energy Plots

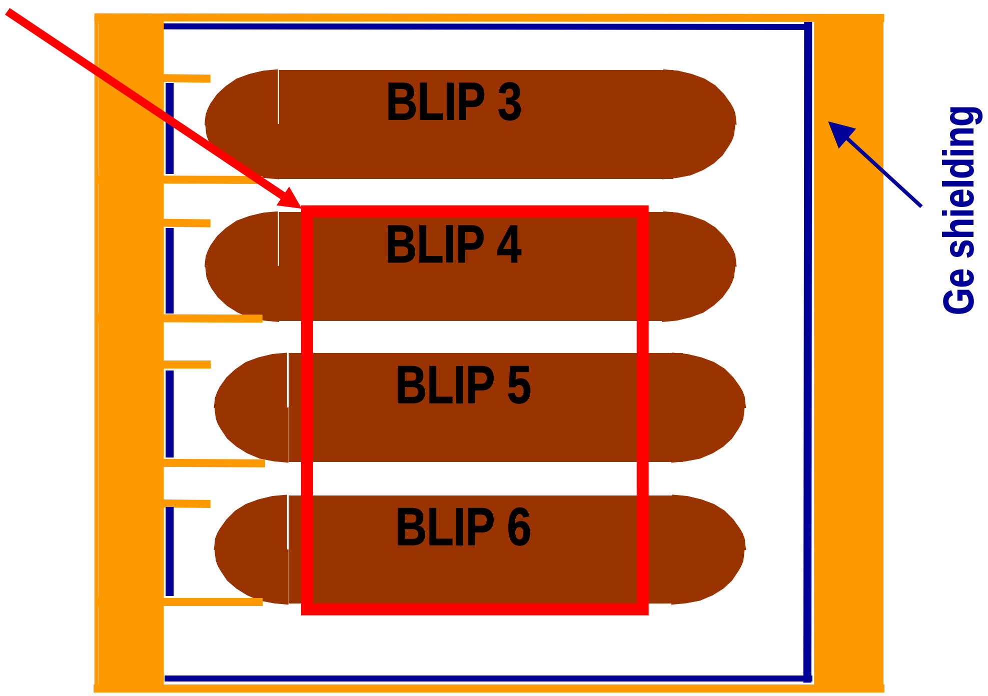
- Events over 10.6 kg-days, anticoincident with muon veto and other detectors
- Gamma Band
- Surface Electron Band
- Nuclear Recoil Bands (dashed lines indicate 90% acceptance region)
- B3 is clearly contaminated (discard in subsequent analysis)



4 x BLIP Tower Schematic (1999 Run)

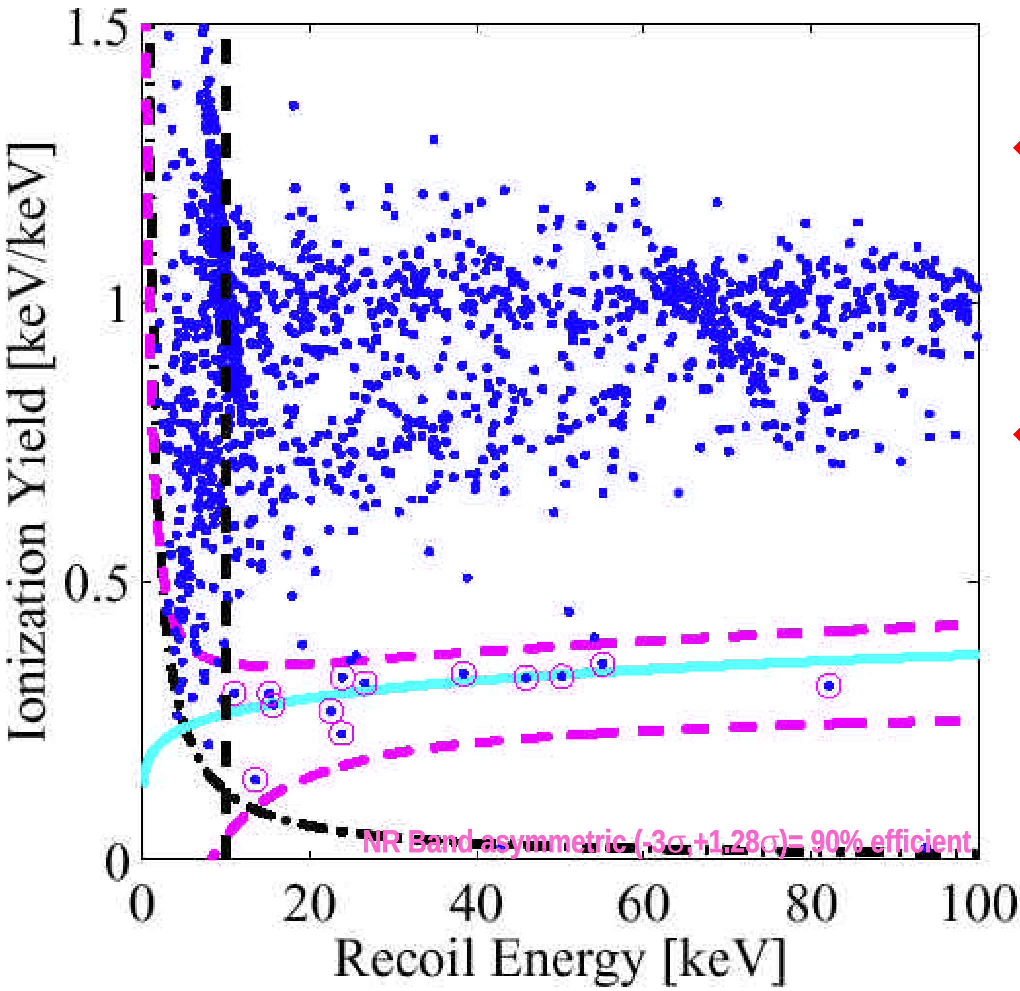
- Self shielding through close pack - spacing 3 mm vertically

Fiducial Region - contains ~0.25 kg of Ge



1999 Run Ge BLIP Data Set Combined

- all single-scatters
- ○ NR candidates



Entire 96 live days operation Ge BLIPs = 10.6 kg-days

- **Gamma and electron bands well separated from NR band**
  - **NR candidates are truly NR's**
- **See a total of 13 events > 10 keV → ~ 1.2 events/kg/day**

This event rate is ~ 1/3 of the DAMA Ann Mod Signal

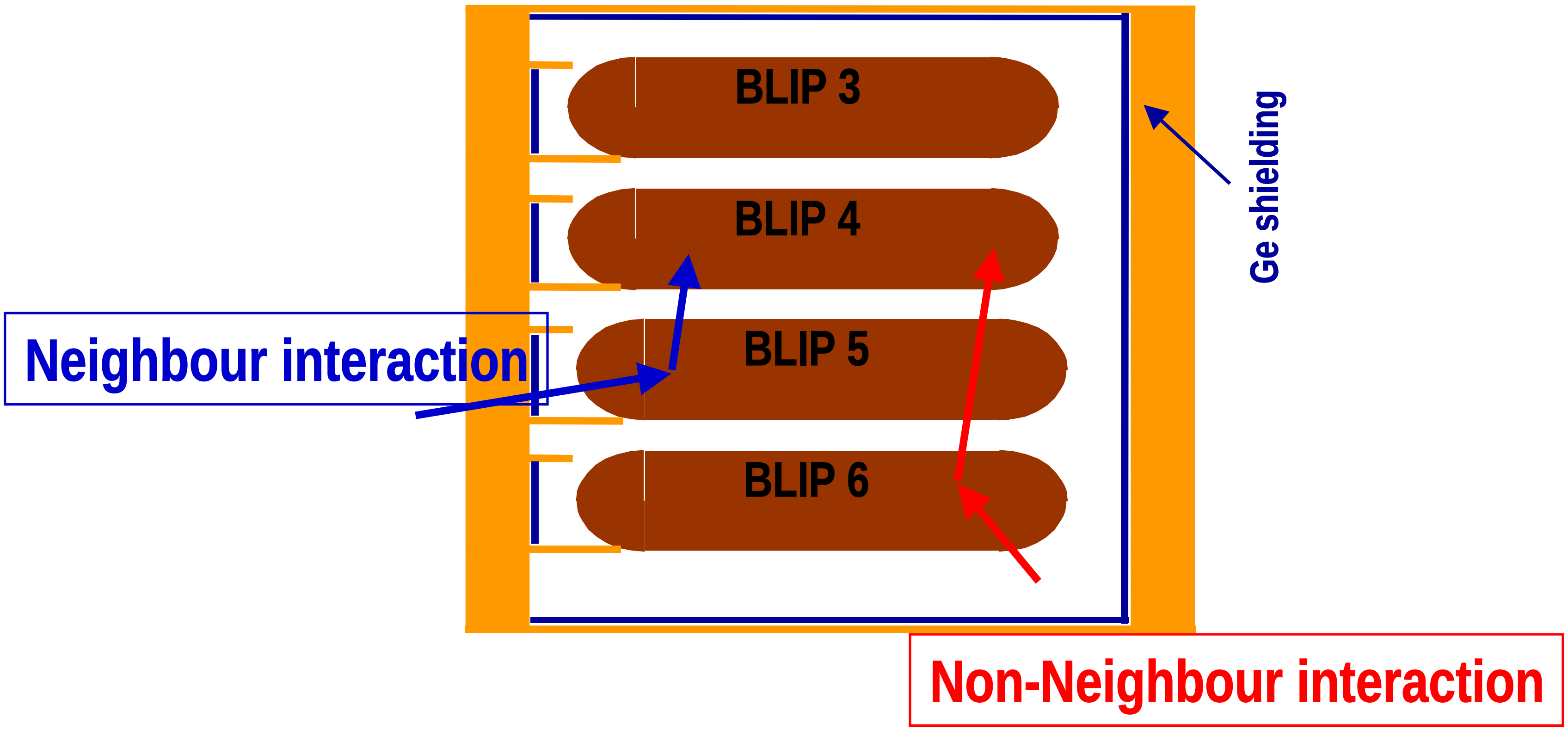
Nuclear Recoil Events

- 13 single NR ~1/3 that expected for the DAMA Ann Mod
- However, we have strong evidence that these events are caused by neutrons
  - 4 multiple scatter nuclear recoils observed in Ge in same data set (**)
  - 4 nuclear recoil events seen during 1.6 kg-days Si data

Observation of Ge multiple/Si single events is consistent with all single nuclear recoil events being due to neutrons

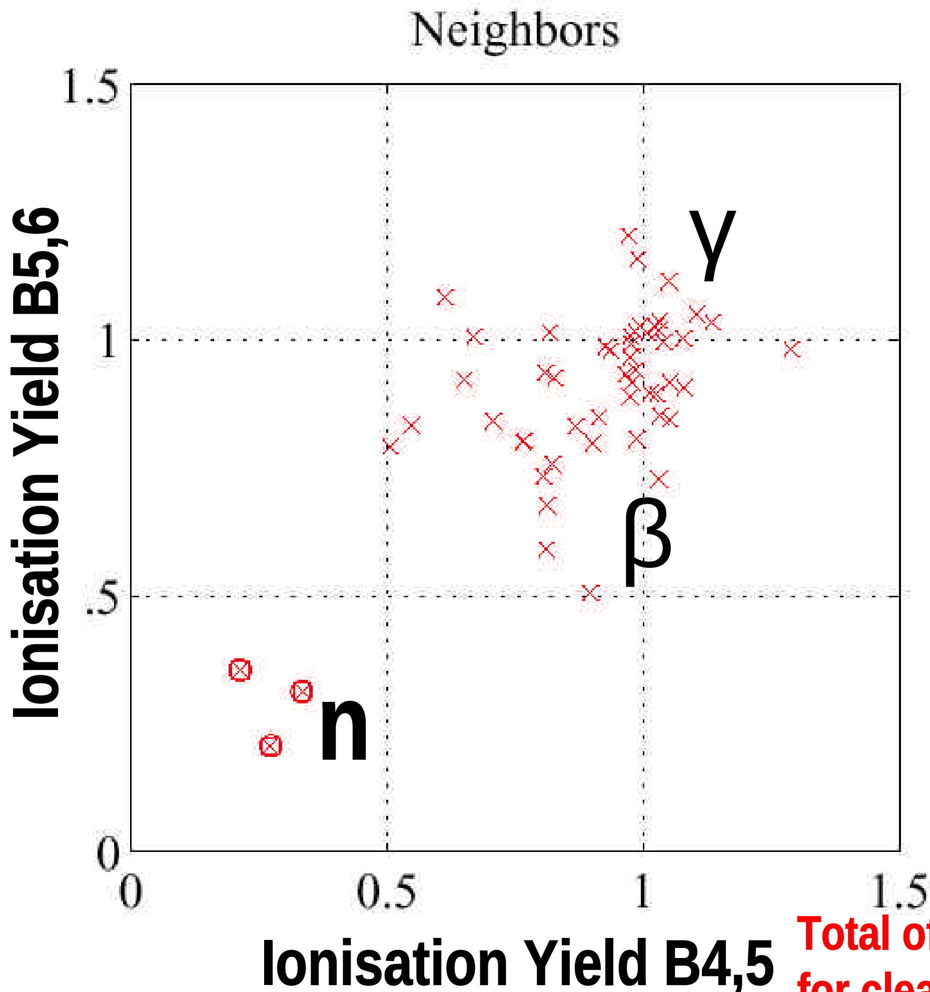
Multiple Events in Tower Run 1999

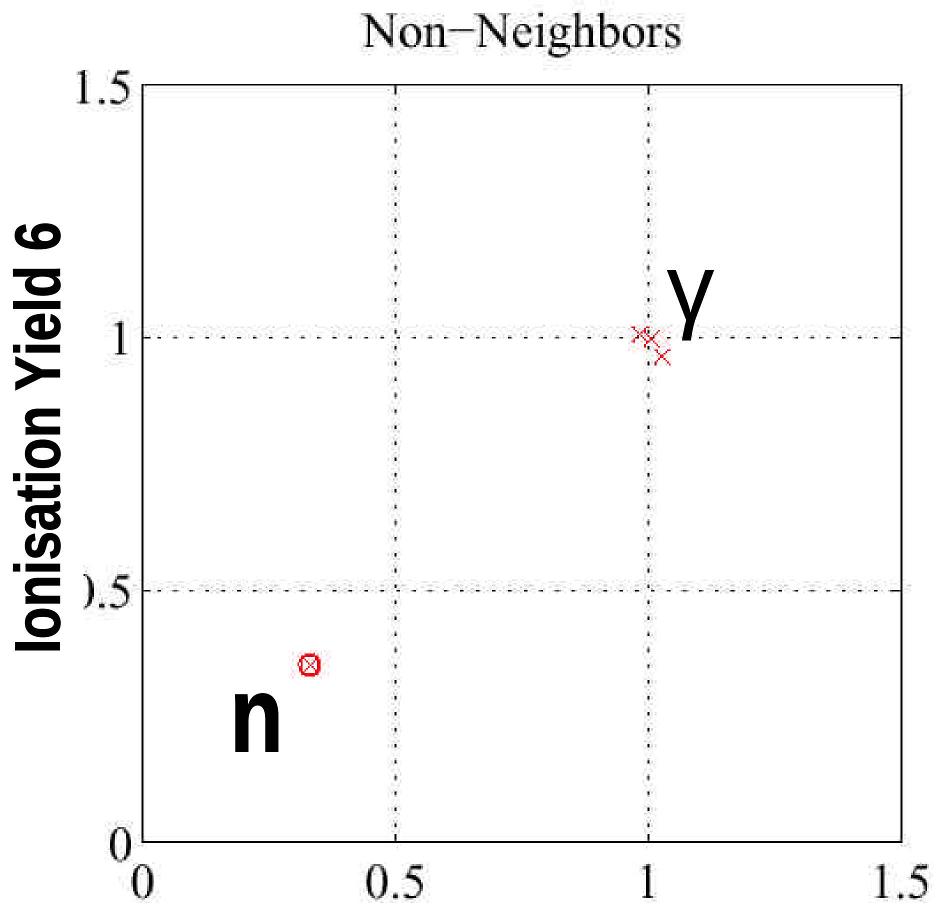
- **Consider Multiple Events in entire run**
  - **Require that both scatters in range 10-100 keV**



Correct Identification of Neutron Multiple Scatters

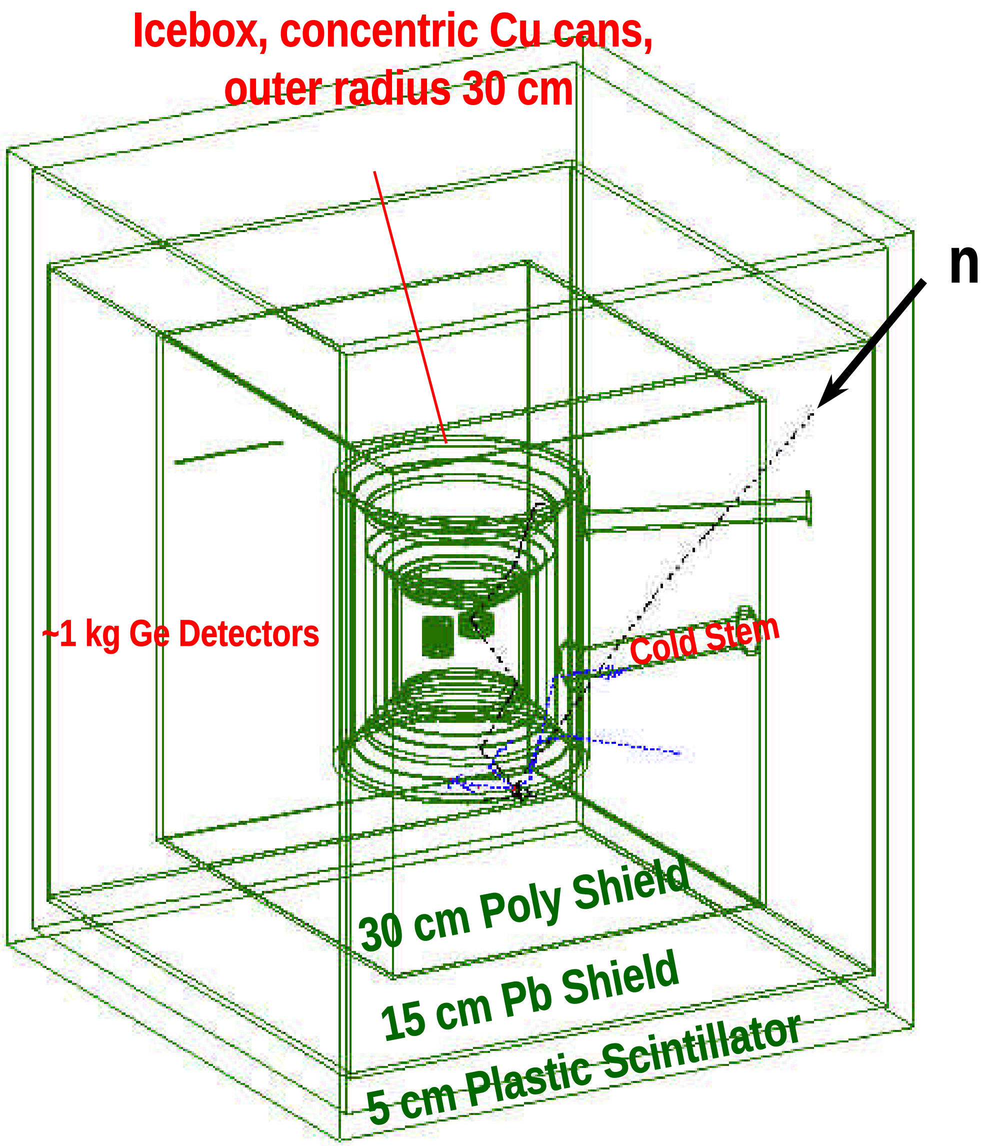
- 10-100 keV Multiple Events (at least one hit in Qinner fiducial)
- Characterise events with Ionisation/Phonon Yield





Total of 4 multiples for clean dets 4,5& 6

Neutron Background Simulation

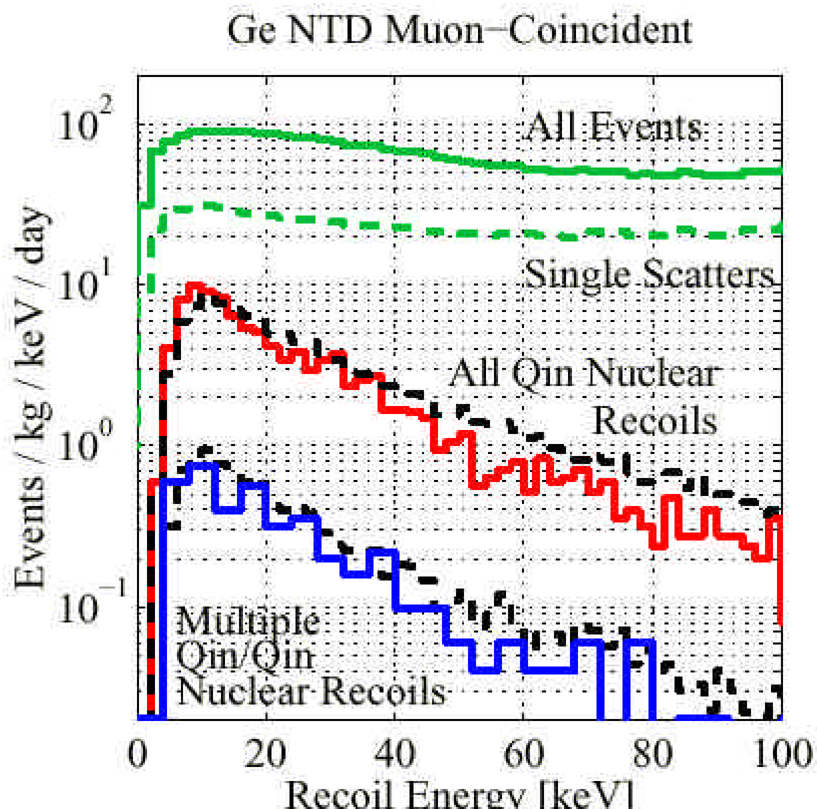


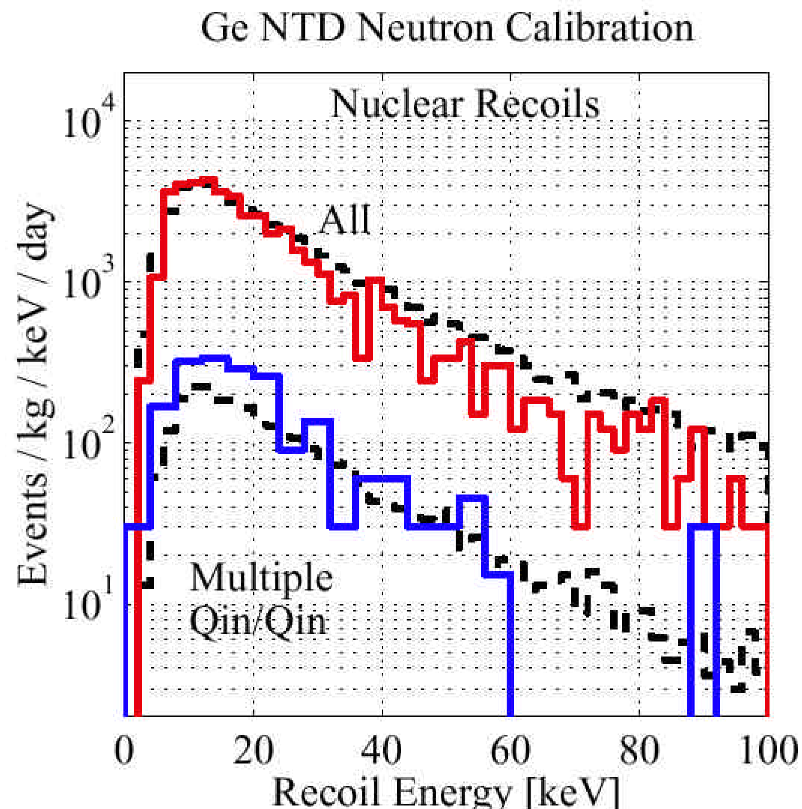
Dimensions give approximate radial thickness of layers

- GEANT shell:
  - geometry
  - input spectra
  - γ/e Tracking
- MICAP and FLUKA packages for neutron interactions
  - MICAP: 10 keV < E_n < 20 MeV
  - FLUKA: E_n > 20 MeV
- Simulates three different neutron sources:
  - “internal” neutrons – generated by muons in Cu cryostat and inner Pb shield veto-coincident
  - “external” neutrons – generated by muons in tunnel walls veto-anticoincident
  - ^{252}Cf neutrons for calibration

Muon-Coincident & Calibration Neutrons

- **Agreement between MC and data is good - no free parameters**
  - **(i) Simulate neutrons generated in Pb/Cu shielding by muons**
  - **(ii) Simulate neutrons from Am/Be source on top of Pb shield (poly out)**



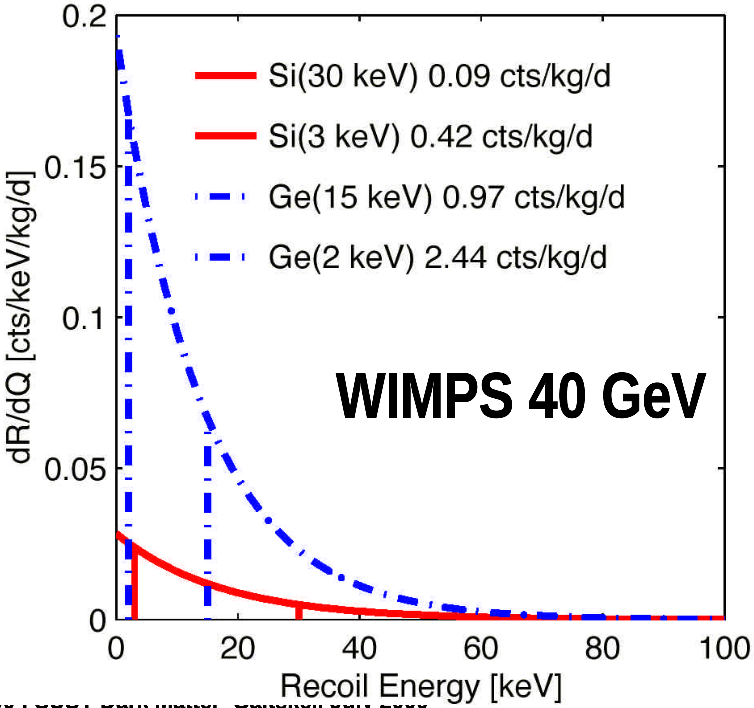


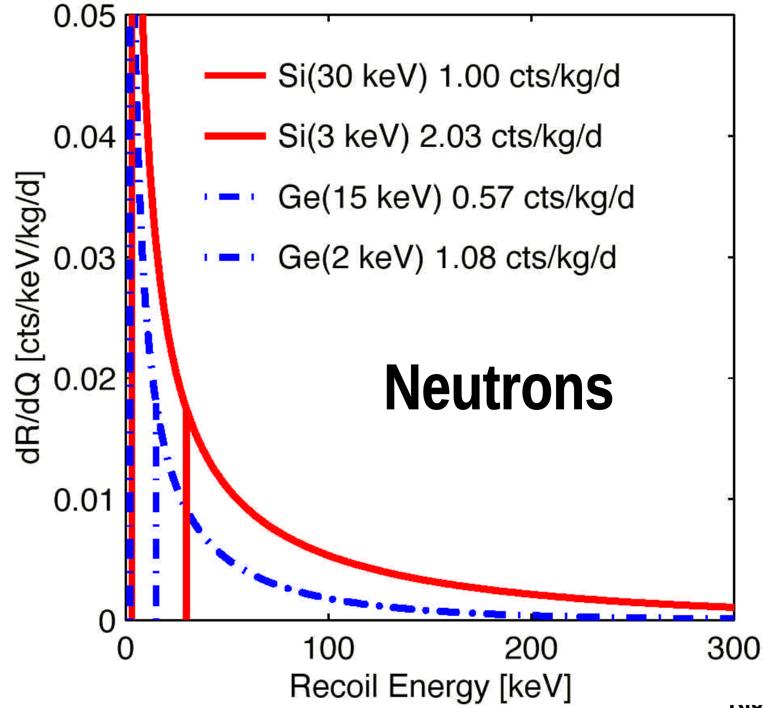
Singles/multiples ratios & shape in MC match data well

~15% syst much smaller than statistical fluctuation in final result

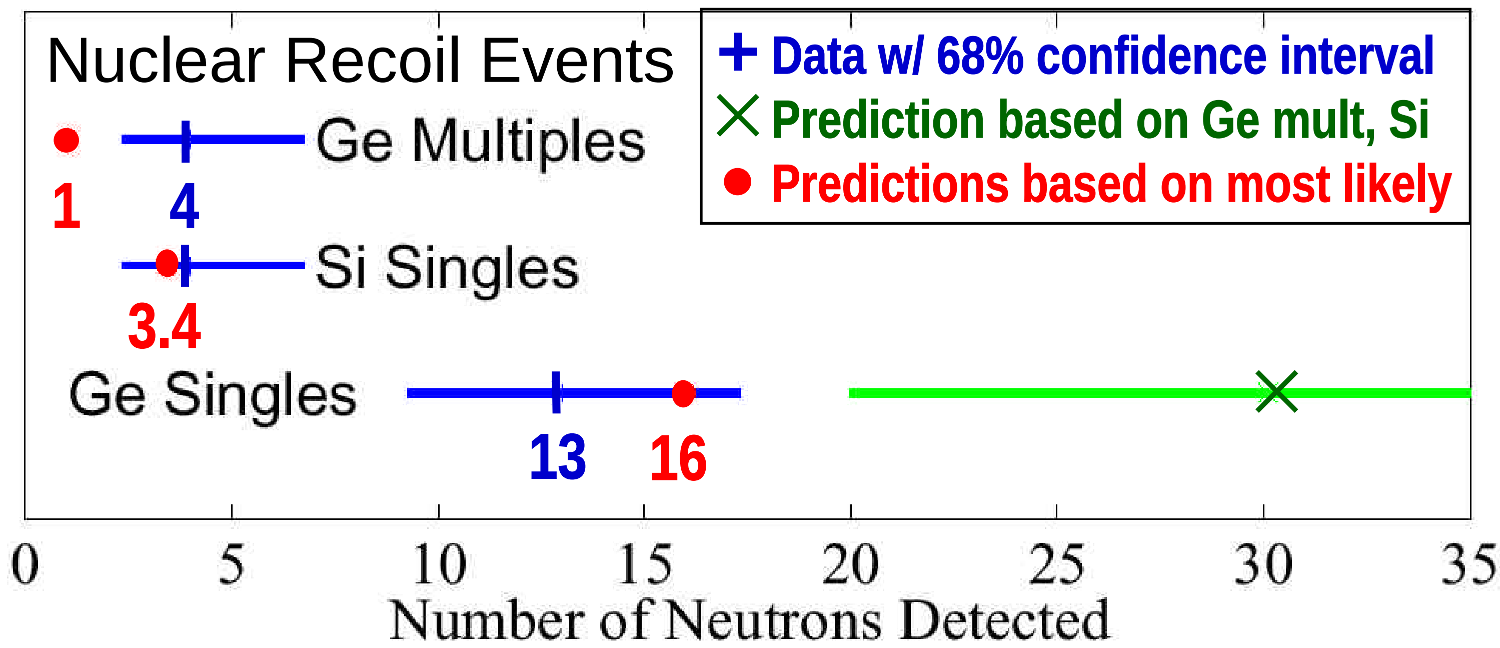
WIMP vs Neutron Sensitivity of Si and Ge

- **Jan-Jun 1998 Si ZIP Run at Stanford Underground Facility**
  - **For neutrons 50 keV - 10 MeV**
    Si has ~2x higher interaction rate per kg than Ge
  - **For WIMPs**
    Si has ~6x lower interaction rate per kg than Ge





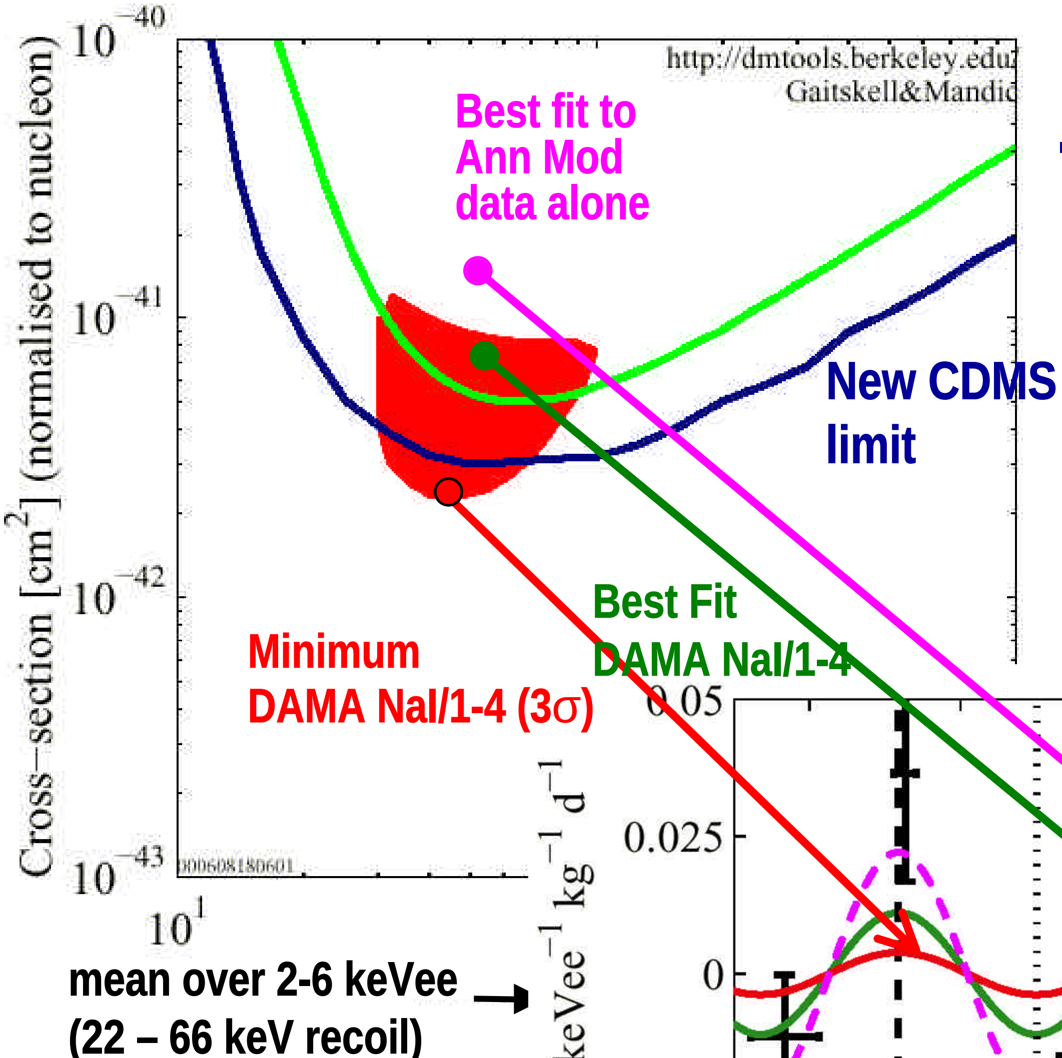
Consistency of Neutron Interpretation with MC

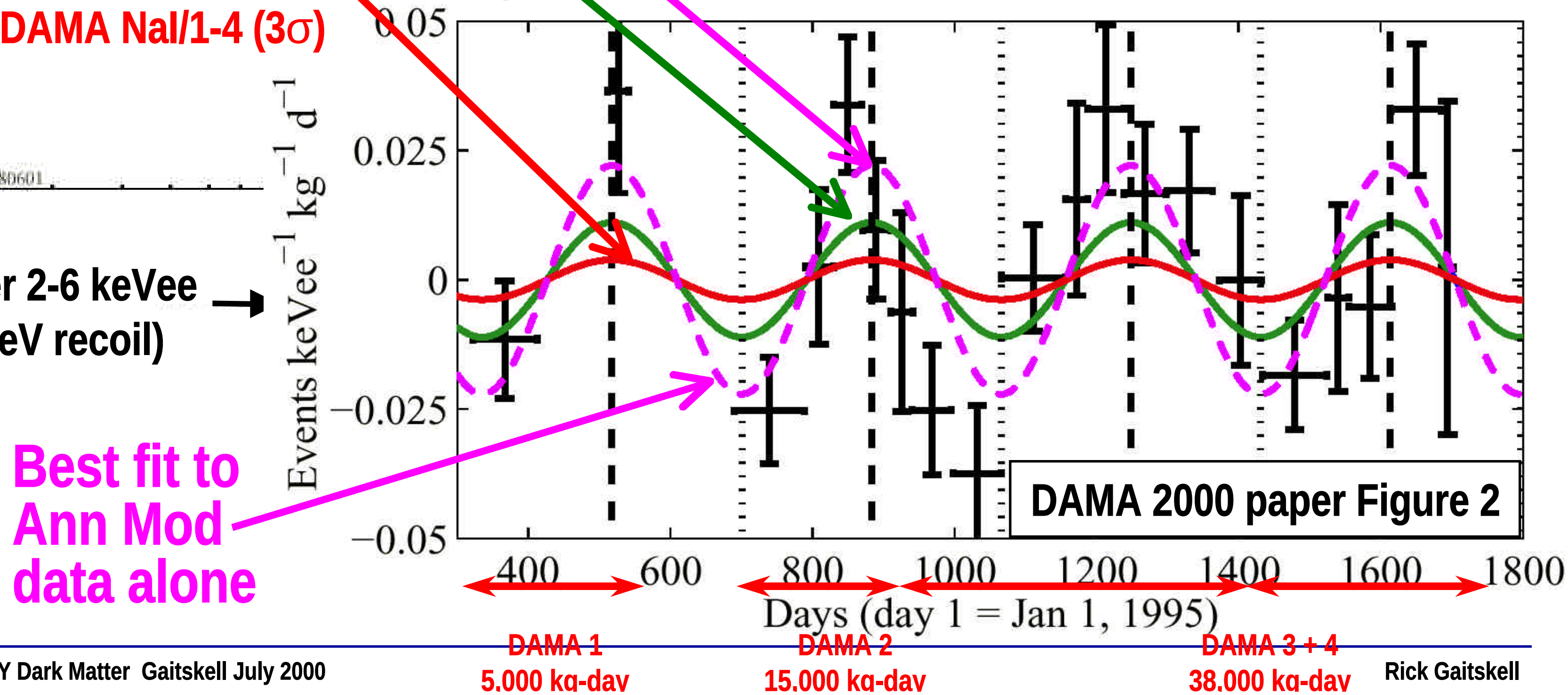


- **Predicted ratios of numbers of events set by Monte Carlo simulations**
- **Ge multiples and Si singles imply large expected neutron background with large statistical uncertainty**
- **Likelihood-ratio test indicates we should expect worse agreement 6% of the time**
- **Energy spectra consistent with expectations for neutrons (also with WIMPs)**

Modulation Amplitude

- **Best-fit WIMP model's expected annual modulation does not appear to fit data; lowest point of 3σ contour is much worse.**
- **Why? Additional constraint applied during max likelihood analysis: DC WIMP signal implied by AC signal must not exceed observed DC count rate**
  best-fit cross-section is decreased





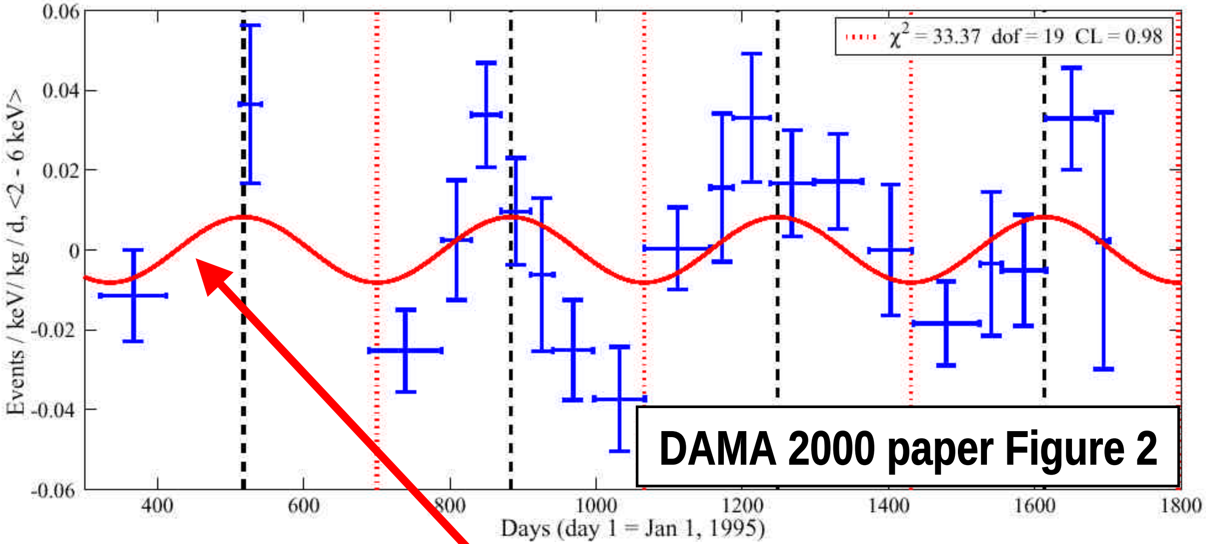
Combined Likelihood CDMS limit & DAMA signal

N_{WIMPs} is number of WIMPs in 10.6 kg-days Ge in CDMS run (E_r>10 keV)

	DAMA (3 year) 58,000 kg-days NaI	Ann. Mod. Signal (fit to Fig 2) m = 50 GeV $\sigma = 14.4\ 10^{-42}\ cm^2$	+Background limit in 2-3 keV bin m = 52 GeV $\sigma = 7.2\ 10^{-42}\ cm^2$
CDMS 1999 10.6 kg-days Ge		$<N_{WIMPs}> = 40$	$<N_{WIMPs}> = 20$ 2.3σ away from best fit to Ann. Mod
Ge singles + Ge multiples + Si singles	$N_{WIMPs} \leq 8$ (90% CL)	99.98%	99.80% CDMS excludes all points in 3σ (~99% CL) region at 75%
Ignore Ge multiples		99.96%	96.80%
Ge singles only	$N_{WIMPs} = 13$ $N_{WIMPs} \leq 19$ (90% CL)	99.5%	59%

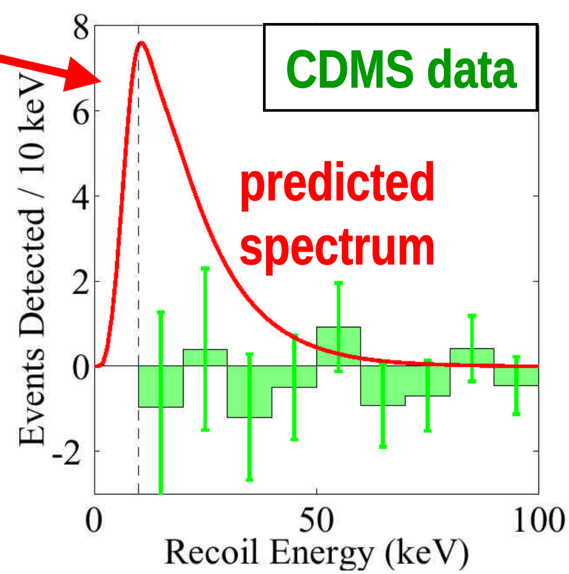
CDMS: Expected sensitivity of multiples (see 1 rather than 4) raises N_{WIMPs} by 50%: ≤ 12 (90% CL)
Combined likelihoods based on CDMS calculated fit to ann. mod. & an inferred likelihood for data when constraint of 2-3 keV bin included (DAMA actual likelihood function not yet made available)

Compatibility of CDMS and DAMA



- **CDMS results incompatible with DAMA Figure 2 data (left) at > 99.98% CL**
- **Estimate full DAMA likelihood function:**
  - **Two experiments are incompatible at 99.8% CL**
  - **Ignore multiple scatters: 96.8% CL**

Best simultaneous fit to CDMS and DAMA predicts too little annual modulation in DAMA, too many events in CDMS



Can CDMS be wrong?

- Could the neutron multiples be contaminated?
  - Calibrations show negligible contamination/Populations are well separated
- Could we be over-estimating our efficiency for nuclear recoils?
  - Good agreement of neutron source calibration and muon coincident neutrons with Monte Carlo predictions
  - Time stability of muon coincident neutrons is good
  - If efficiency is wrong cut multiples would be reduced by more than singles
- Can the Monte Carlo predictions of neutron scattering ratios (Ge multiples and Si singles to Ge singles) be wrong?
  - MC predicts experimentally observed ratios (muon coin. & calib neutrons)
  - Final limits depends on ratios which are (mult/single)~9% in all pops. studied
- What about spectrum shape of unvetoed neutron events?
  - What if unvetoed spectrum is not that predicted by Monte Carlo?
  - However, neutron multiples spectrum agrees with singles spectrum
  - If unvetoed neutron spectrum is factor of 2 harder, then CDMS 90% CL moves up in cross section by less than factor 2

Non-Scalar Couplings

- **Preceding analysis and comparison of (mass,cross-section) limits for NaI, Ge and Si targets assumed scalar coupling of WIMPs**
  - **SUSY couplings at this level dominated by coherent cross section**
  - $\sigma \sim A^2$
  - **I (A=127), Ge (A=72), Si (A=28)**
- **Axial vector scattering**
  - **Comparison of Na and I (both mono-isotopic odd-p) and Ge/Si target (8% ^{73}Ge , 5% ^{29}Si both odd-n) must be model-dependent**
  - **DAMA interaction rates well above current SUSY (axial coupling) predictions (~50x)**
- **For CDMS nuclear recoil events alone under axial interpretation**
  - **Si events must be neutrons since per mole Si is about 5x less sensitive than Ge to axial WIMPs (no theoretical ambiguity here)**

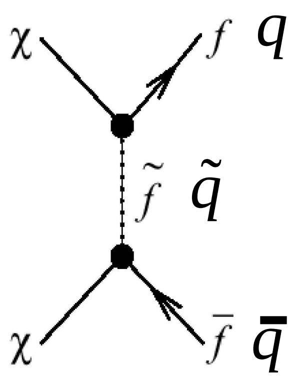
Conclusions and Future Plans

- **CDMS I probing supersymmetry region**
  - Results for scalar-interacting (σ~A^2) WIMPs are incompatible with DAMA signal at very high confidence
  - PRL published (also available astro-ph/0002471)
- **2000 Run underway**
  - 3 germanium and 3 silicon detectors - better background subtraction
  - Additional neutron moderator to cut background by ~2.3x
- **CDMS II full funding (99-05) approved by NSF & DOE**
  - Construction already underway at Soudan mine, Northern Minnesota
  - "First Dark" in 2001
  - CDMS detectors have the potential for tremendous additional reach: 100 times lower than current limits ~1 event / kg / year

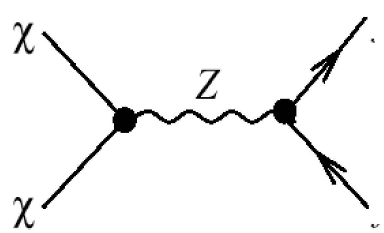
R. Abusaidi et al., Phys. Rev. Lett. 84, 5699 (17June2000) astro-ph/0002471
Also PRD to follow + Thesis Golwala

Neutralino Couplings

- **Annihilation (many channels)**
  - Spin Independent - Scalar

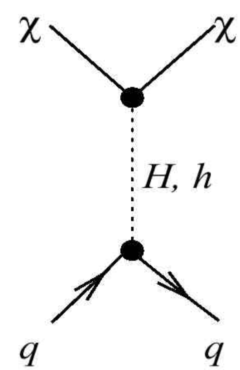


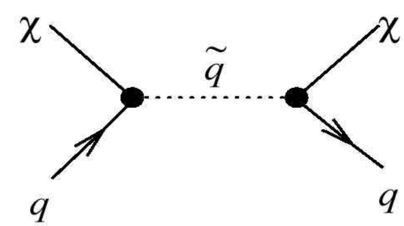
  - Spin Dependent - Axial Vector



a.d.t.

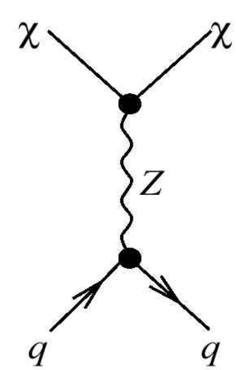
- **Scattering from Nuclei** (A nucleons)
  - Spin Independent - Scalar

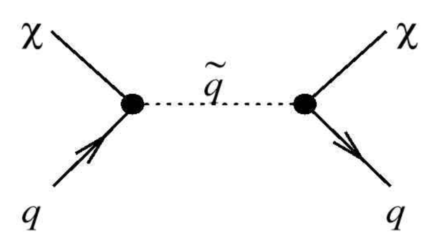




Coherent $\sigma \sim A^2$ -->dominates

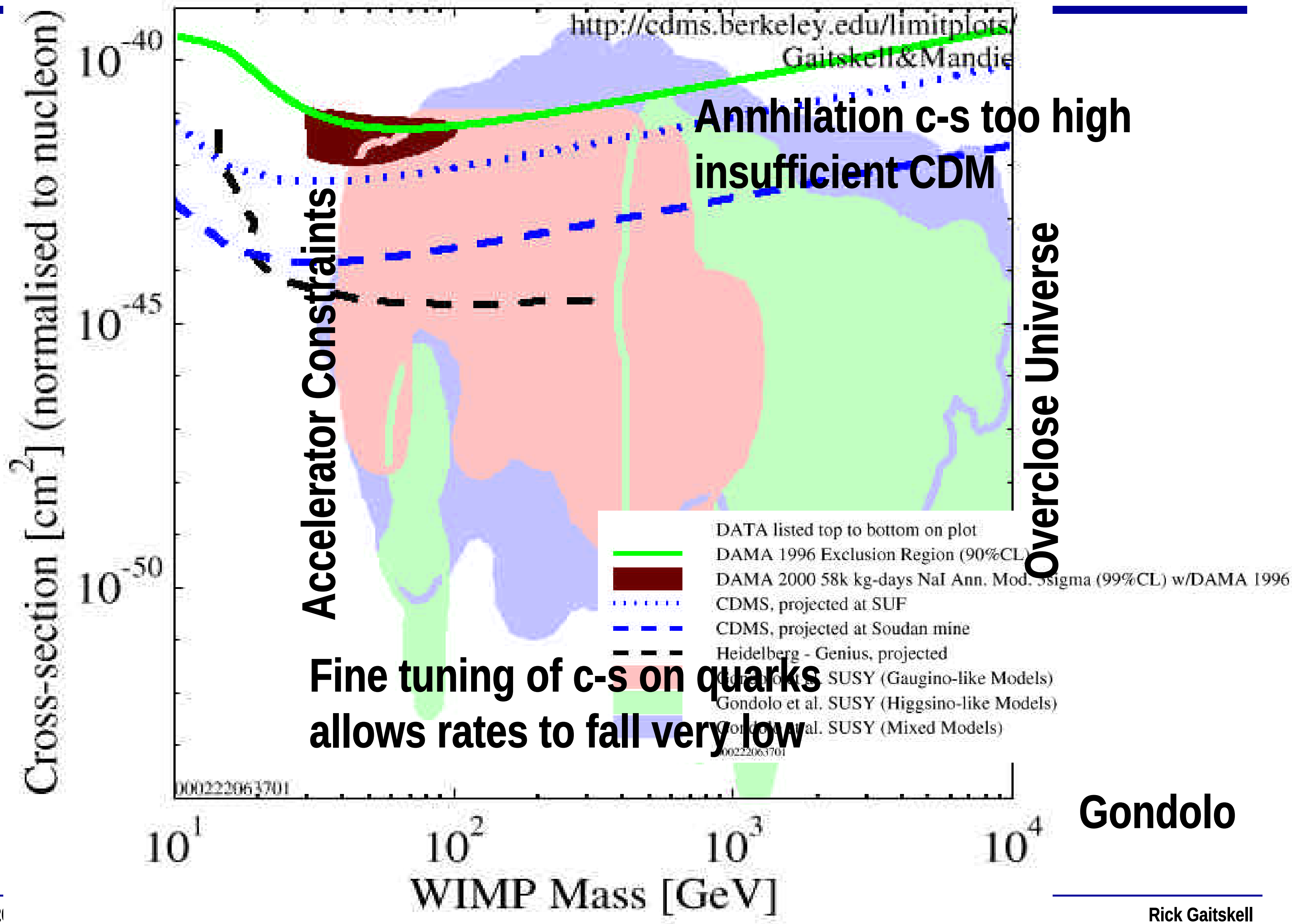
  - Spin Dependent - Axial Vector





time →

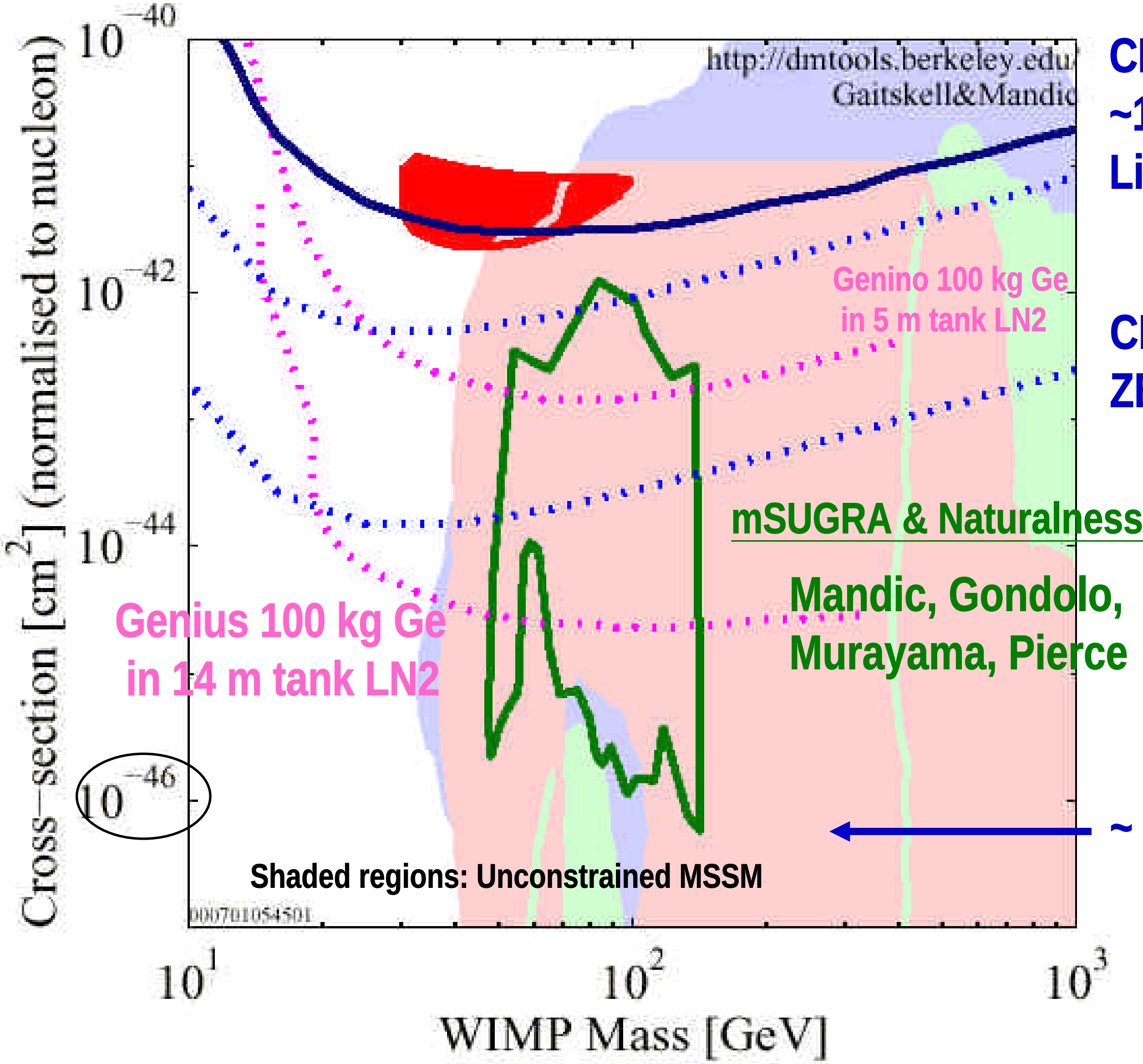
SUSY-unconstrained MSSM (!) - Ignore Naturalness



Gondolo

Future Reach / Lower limit on quark σ

http://dmtools.berkeley.edu
http://dmtools.in2p3.fr



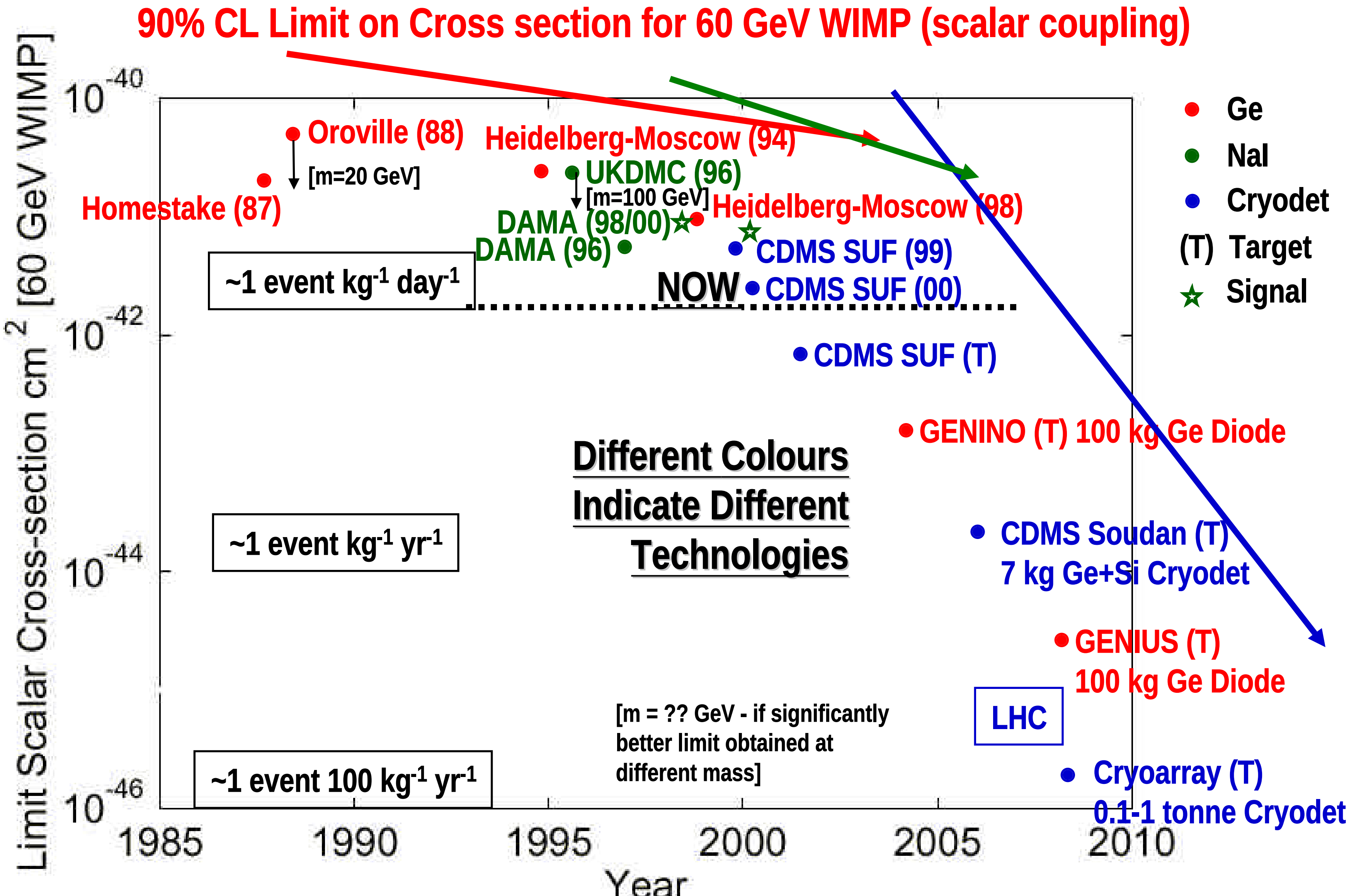
CDMS Latest Feb 2000
~1 event/kg/day
Limited by shallow site

CDMS II 5 kg Ge at Soudan
ZEPLIN 6 kg Xe at Boulby

$0 < M_3 < 1000$ GeV
$95 < m_0 < 1000$ GeV
$-3000 < A_0 < 3000$ GeV
$1.8 < \tan(\beta) < 25$
sign of μ
$0.025 < \Omega h^2 < 1$

~ 1 event/100 kg/year

Direct Detection: History & Future



Not meant to be a complete list - see http://dmtools.berkeley.edu

Future

- **Strategies for Improvement in Detector Reach & Signal Identification**
  - **High Cleanliness**
    - **GENIUS is ~3000 improvement in background over existing HP Ge (Similar to Solar Neutrino Environments, but to few keV)**
    - **Will require new techniques for assaying backgrounds in materials**
  - **Gamma/Electron Background Discrimination**
    - **Share some of improvement budget between improved discrimination and cleanliness**
    - **--> 100-1000 kg event by event discriminating detectors**
  - **Modulation, but using above and below pivot point**
    - **Importance of "Beam Off" in analysis**
    - **Only uses ~5% of mass**
  - **Directionality of Recoils**
    - **Gas TPC (can we achieve target mass?)**

“Physics in Collision”: Conclusion

“Physics in Cooperation”

- **Interplay between “Precision” Cosmology and Accelerator and Non-Accelerator Particle Physics**
  - **WIMPS / Neutrinos / Cosmological Constant / Quintessence / Axions Direct Detection of LSP Dark Matter**
- **CDMS I Results**
  - **Demonstrate power of event by event discrimination**
    - **10 kg-day vs 58,000 kg-days**
  - **CDMS I & DAMA results are incompatible**
    - **Further investigations**
- **Experiments now probing SUSY parameter space**
  - **100 kg-year would sweep out all minimalSUGRA space**
    - **Low energy backgrounds**
      - **new challenge, need to set up new counting facilities & greater network**
    - **Discrimination**
      - **Extra leverage to span 4 orders of magnitude**