SEARCHES FOR WIMP DARK MATTER:

EXPERIMENTS "TO DATE"

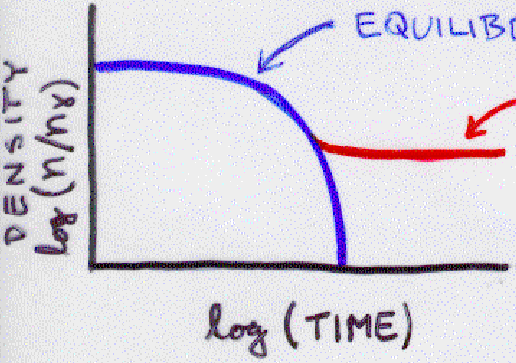
DAN AKERIB
CASE WESTERN RESERVE UNIVERSITY
CDMS COLLABORATION

Akerib - 02

Akerib - 03

WIMPs

- **EARLY UNIVERSE: PRODUCTION**



EQUILIBRIUM $n \sim e^{-mc^2/kT}$

RELIC DENSITY $\sim O(\rho_{CRITICAL})$

FOR $M \sim 10 - 1000$ GeV

$\sigma \sim$ WEAK

SUSY/LSP

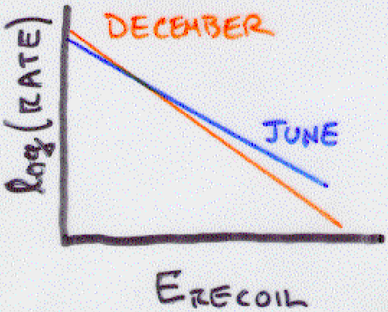
AND $T_{FREEZE\text{-}OUT} \sim \frac{1}{20} M$

$\Rightarrow$ NON-REL (COLD)

- **GALACTIC HALO: DETECTION**

WIMP-NUCLEUS ELASTIC SCATTERING

- MAXWELLIAN HALO $\frac{dn}{dv} \sim v^2 e^{-v^2/\sigma_v^2}$
- RECOIL ENERGY $\Delta E = \frac{M_N M_W^2}{(M_N + M_W)^2} v^2 (1 - \cos\theta)$
- $\rho_{HALO} = 0.3$ GeV/cm^3



RATES $\lesssim 1$ /kg/d

$E_{RECOIL} \sim 10 - 100$ keV

~~FEATURELESS SPECTRUM~~

$\Rightarrow$ VARY $M_{NUCLEUS}$; SD/SI

ANNUAL MODULATION BERNABEI

ALSO, DIURNAL MODULATION ZACEK

Ge IONIZATION DETECTORS

- ORIGINALLY FOR ββ DECAY ⇒ LOW THRESHOL
- ADVANTAGES:

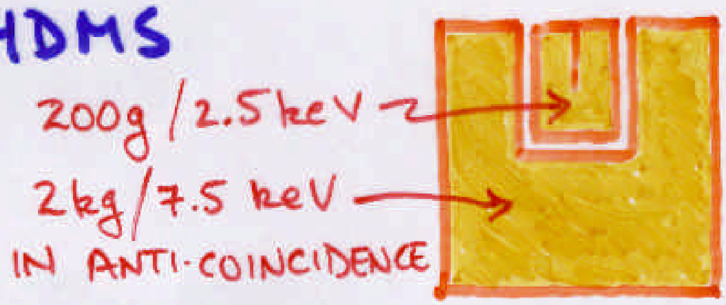
  GOOD COUPLING – SPIN INDEPENDENT
  HIGH-PURITY ⇒ LOW INTRINSIC BKG.
  KILOGRAM TARGET MASSES
  QUENCHING FACTOR = 0.3
  STRAIGHTFORWARD / STABLE TECHNOLOGY

- MANY SUCCESSFUL EXPERIMENTS
- FRONT RUNNERS / STILL ACTIVE:

HEIDELBERG/MOSCOW (GRAN SASSO)

2.8 kg   9 keV   0.042 EVTS/kg/keV/d [15-45keV
≡ d.r.u.

HDMS



4 x BKG REDUCTIO IN PROTOTYPE

FURTHER SUPPRESSIO IN PROGRESS

IGEX COLLABORATION (CANFRANC)

COSME   234 g   1.6 keV   0.6 dru [2-15 ke
IGEX/RGII   2.2 kg   4 keV   0.3 dru [4-10 ke
NOISE REDUCTION → 0.1 dru

Ge LIMITS

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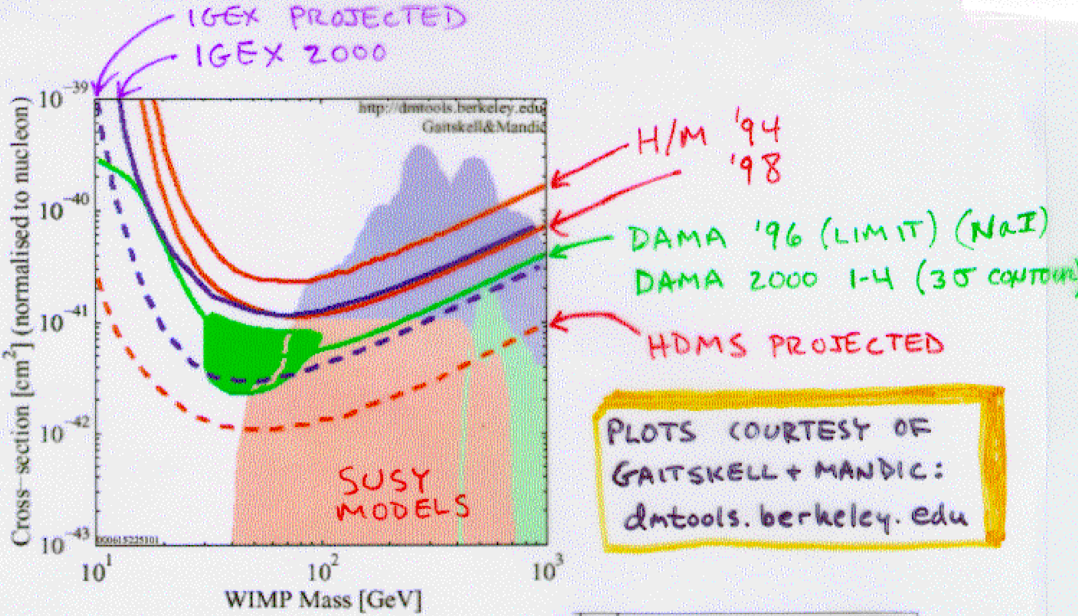
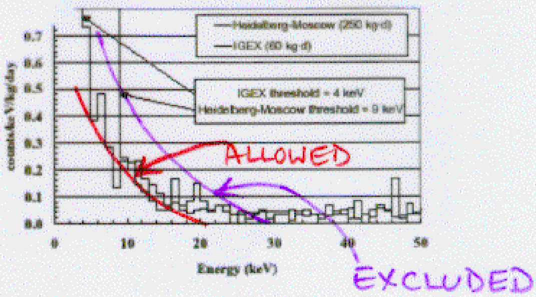
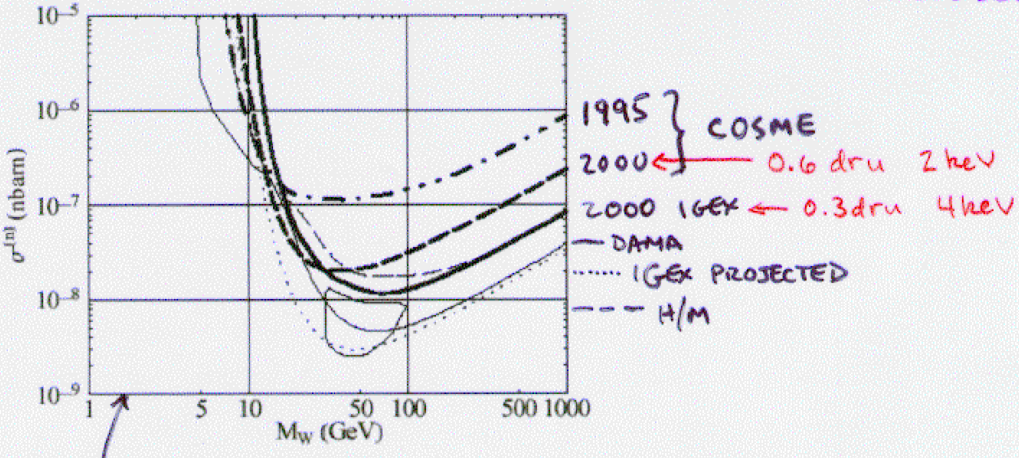


PLOTS COURTESY OF GAITSKELL + MANDIC: dmtools.berkeley.edu





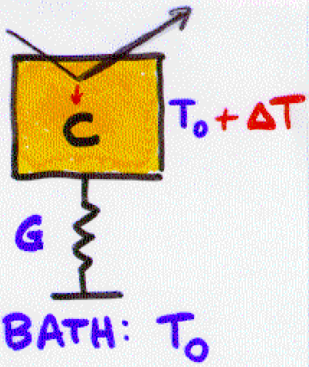
COMPILATION: A. MORALES hep.ex/0002053

Ge diodes

DATA listed top to bottom on plot

- Heidelberg–Moscow, 1994
- IGEX exclusion limit
- Heidelberg Moscow, 1998
- DAMA 1996 Exclusion Region (90%CL)
- IGEX projected exclusion limit (for 1kgyr)
- DAMA 2000 58k kg–days NaI Ann.Mod. 3sigma,w/o DAMA 1996 limit
- Heidelberg DMS, projected
- Corsetti & Nath, mSUGRA predictions
- Gondolo et al. SUSY (Gaugino–like Models)
- Gondolo et al. SUSY (Higgsino–like Models)
- Gondolo et al. SUSY (Mixed Models)

CRYOGENIC DETECTORS



- $\Delta T = \frac{E_{RECOIL}}{C} e^{-t/(C/G)}$
- LONG, COMPLEX DEVELOPMENT

  LOW TEMP THERMOMETRY

  NTD Ge
  SC TES

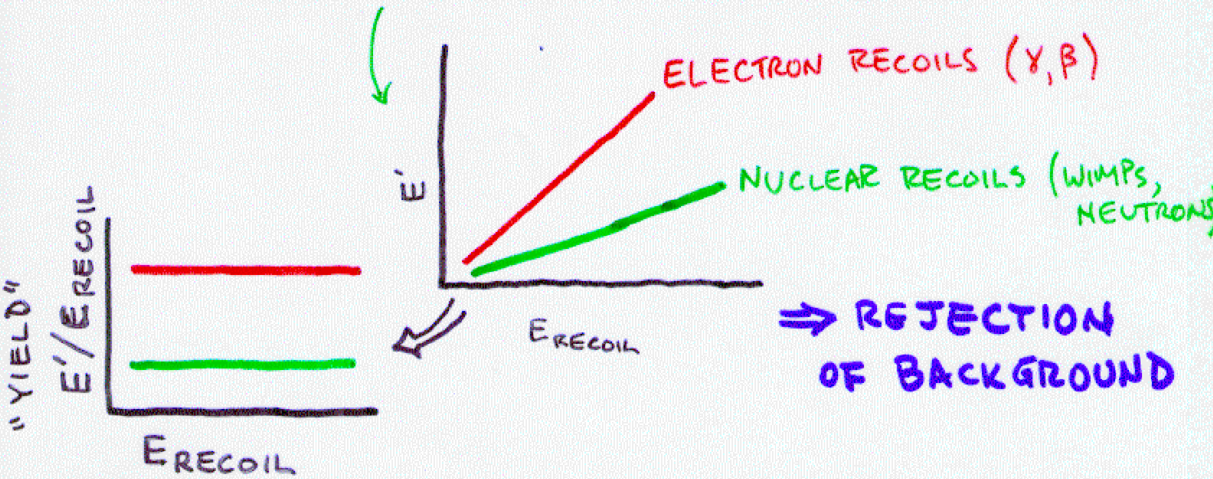
  OPERATE @ 10 mK

  MODEST MASS 0.1 – 1 kg, TYPICALLY – BUT RISING
- ADVANTAGES

  VARIETY OF TARGET MATERIALS
  UNITY QUENCHING FACTOR
  ~keV THRESHOLD

  COMBINE WITH OTHER MEASUREMENTS: RECOIL DISC.

  IONIZATION
  SCINTILLATION } SIMULTANEOUS ENERGY MEASUREMENT



CRYOGENIC DETECTORS

(THERMAL ONLY – NO DISCRIMINATION)

MIBETA (GRAN SASSO)

PRIMARILY ββ DECAY   20 × 340g TeO_2 w/NTD

AT 6.8 kg, LARGEST MASS IN OPERATION

3.9 kg-day FOR 1 DETECTOR 10keV 3dru

DIRECT CONFIRMATION OF UNITY Q.F. (WITHIN 5%) → CUORE – V. ZACEK

LiF/TOKYO

8 × 21g = 168g w/NTD

^{19}F HAS BEST SD COUPLING

HIGH BACKGROUND/SHALLOW SITE

→ IMPROVEMENTS TO μ VETO, SHIELDING IN PROGRESS

BUT LOW THRESHOLD ⇒ COMPETITIVE AT LOW MASS WITH 10 d EXPOSURE

ROSEBUD (CANFRANC)

2×25g + 50g Al_2O_3 w/NTD

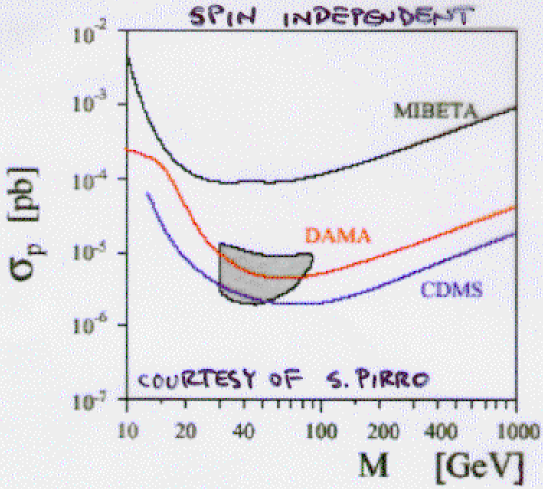
EXTREMELY LOW THRESHOLD: 300eV

FEATURES 2g ENRICHED ^6Li: $^6Li(n,\alpha)^3H$

SHORT RUNS ⇒ BACKGROUND SUPPRESSION (~5 dru)

EXTEND TO Ge, Al_2O_3; BGO, $CaWO_4$

CRYOGENIC LIMITS

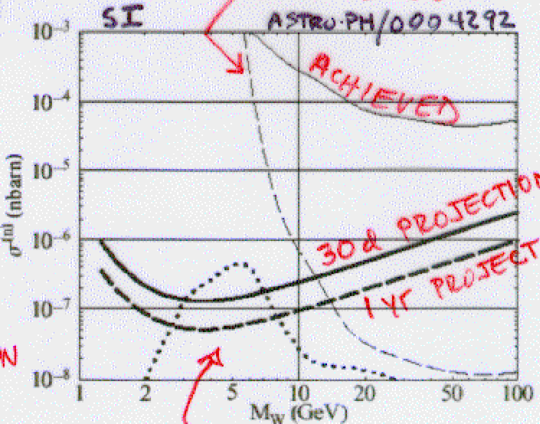


MIBETA

TeO_2

(TO REDUCE RADON DAUGHTERS, THRESHOLD 10 → 5 keV)

COMBINED Ge LIMIT



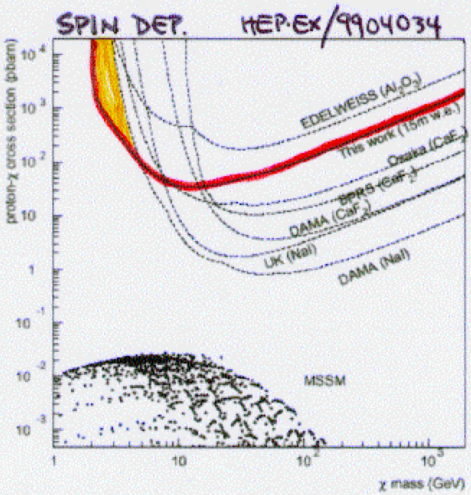
UNCONSTRAINED MSSM (GABUTTI ET AL, '96)

ROSEBUD

Al_2O_3

(SAPPHIRE)

FACTOR 10-100 NEEDED IN BACKGROUND SUPPRESSION



LiF/TOKYO

HIGH BACKGROUND/SHALLOW SITE

LOW THRESHOLD

CDMS EXPERIMENT

1999 DATA

4 x 170g Ge → THERMAL: NTD / → IONIZATION "BLIPs"

10.6 kg-d 10 keV THRESHOLD (RECOIL ENERGY)

1998 DATA

100g Si → THERMAL: W TES / → IONIZATION "ZIPs"

1.6 kg-d

STANFORD SITE

17 MWE DEPTH ⇒ SIGNIFICANT μ FLUX ⇒ γ, n

Pb SHIELD + POLYETHYLENE n MODERATOR + ACTIVE μ VETO

NEXT:

SOUDAN MINE - CDMS II

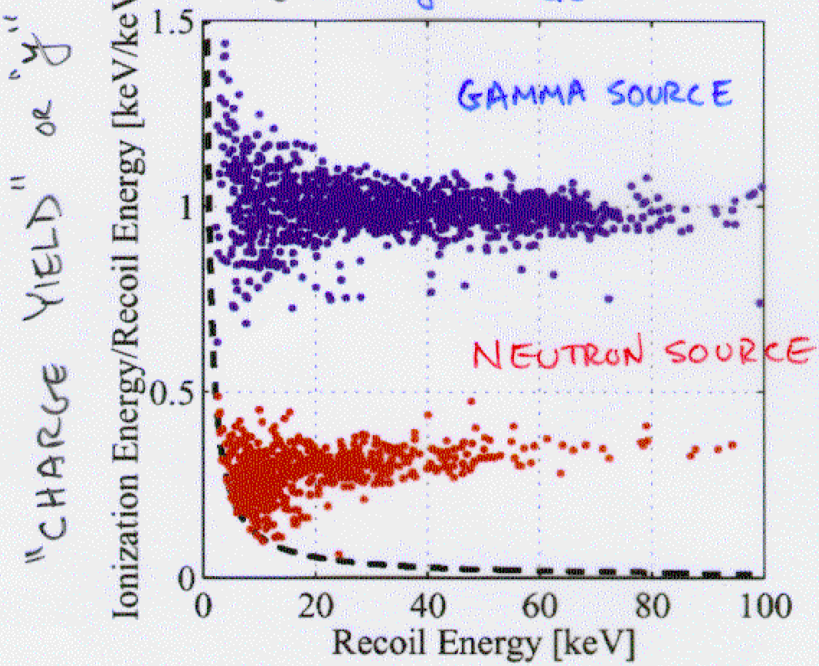
21 x 250g Ge

21 x 100g Si

TES + IONIZATION : ZIPs

BLIP PERFORMANCE

- NTD READOUT
- 167-gram Ge TARGET



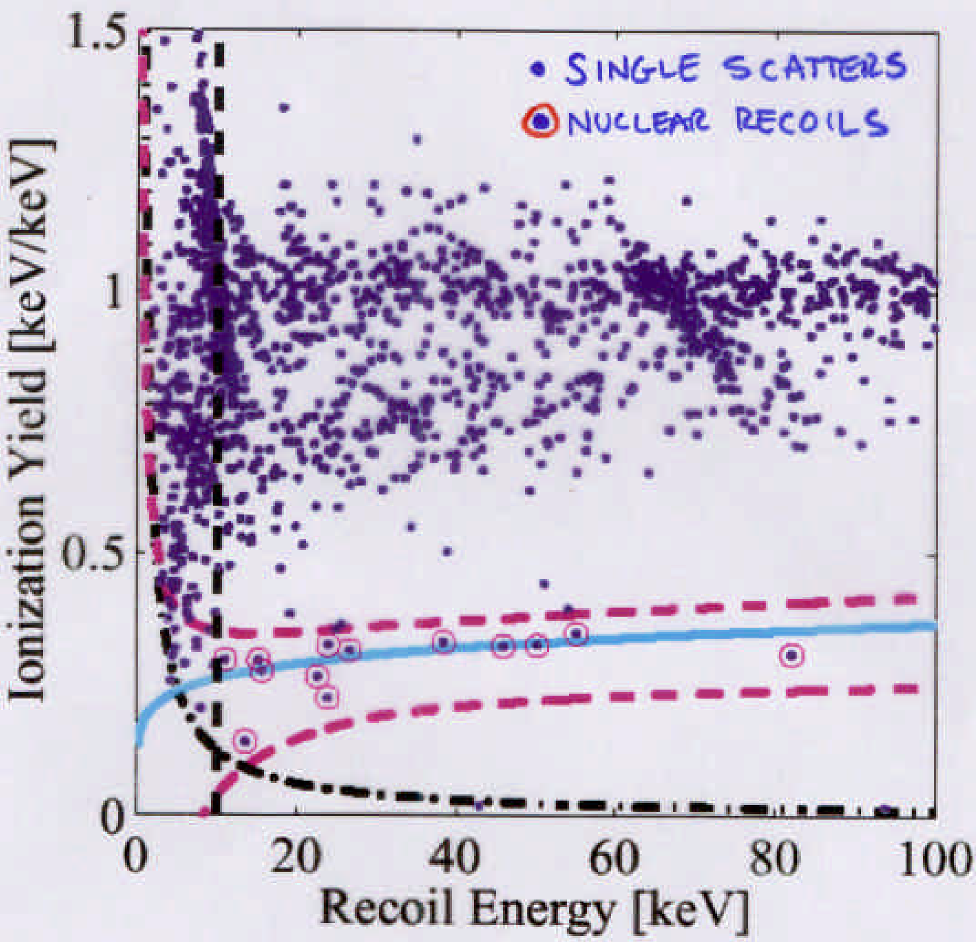
→ EXTREMELY GOOD DISCRIMINATION OF ELECTRON AND NUCLEAR RECOILS

1999 COMBINED DATA

BLIPS 4,5,6

Akerib - 11

- 45 LIVE DAYS ⇒ 10.6 kg-d EXPOSURE
- WELL SEPARATED γ, β, n.r. BANDS



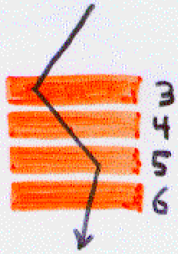
⇒ 13 EVENTS WITH E > 10 keV

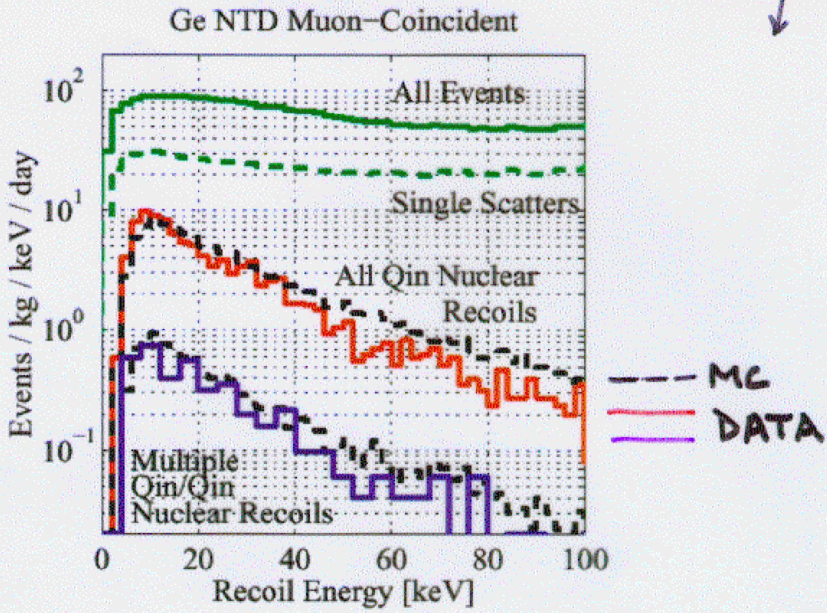
~ 1 EVENT / kg-d

~ DAMA REGION

μ-INDUCED NEUTRONS

- EXPECT μ-COINCIDENT NEUTRONS
- NEUTRON MEAN·FREE·PATH ~1 CM
- MULTIPLE SCATTER RATE A GOOD PREDICTOR OF SINGLES





⇒ USE COINCIDENT TO CHECK MC

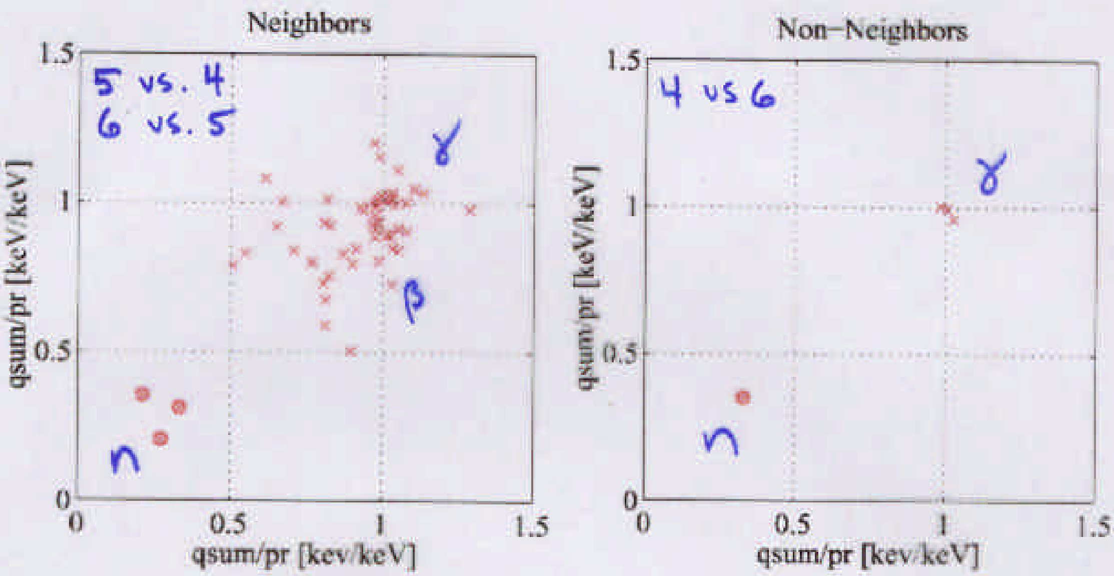
⇒ GET AGREEMENT TO ~10% ON MULTIPLE/SINGLES RATIO

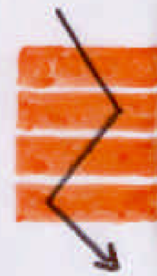
⇒ APPLY CONSTRAINT ON SAME RATIO IN DARK MATTER DATA

NEUTRON ID CROSS CHECKS

MULTIPLE SCATTER EVENTS

- DANGER: OVERESTIMATE OF MULTIPLE N.R.'S THROWS OUT A TRUE SIGNAL
- PLOT YIELD vs. YELD FOR ALL MULTIPLE SCATTERS





→ SEE 4 n-n MULTIPLES → CONSTRAINS # OF SINGLE SCATTERS

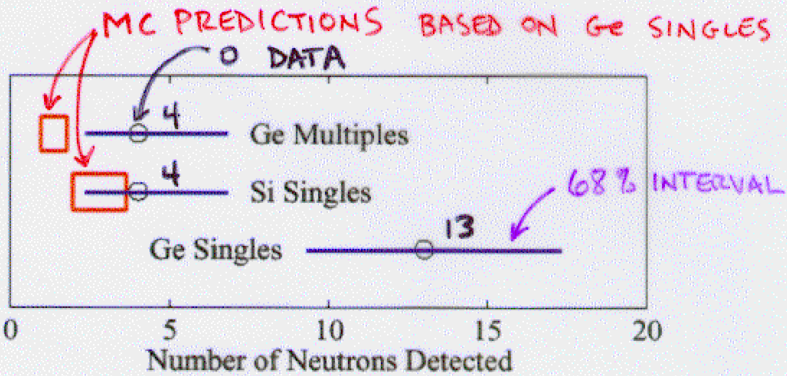
→ NO n-β OR n-γ TAILS

WORRY ABOUT LOW CHARGE YIELD OF SURFACE EVTS (NON-PENETRATING ELECTRONS E<100keV

⇒ β LOOKS LIKE n

NUCLEAR RECOIL SUMMARY

μ-ANTI-COINCIDENT NUCLEAR RECOILS



APPLY 'FELDMAN-COUSINS' LIKELIHOOD ANALYSIS

INPUT: Ge SINGLES RECOIL SPECTRUM E_i

\# Ge MULTIPLES

\# Si EVENTS (ALL SINGLES)

STANDARD HALO PARAMETERS

MC CONSTRAINED RATIOS

$$\frac{\text{Ge MULTIPLES}}{\text{Ge SINGLES}}, \quad \frac{\text{Si SINGLES}}{\text{Ge SINGLES}}$$

SPIN-INDEPENDENT WIMP-NUCLEON SCATTERING

VARY: OVERALL NEUTRON NORMALIZATION

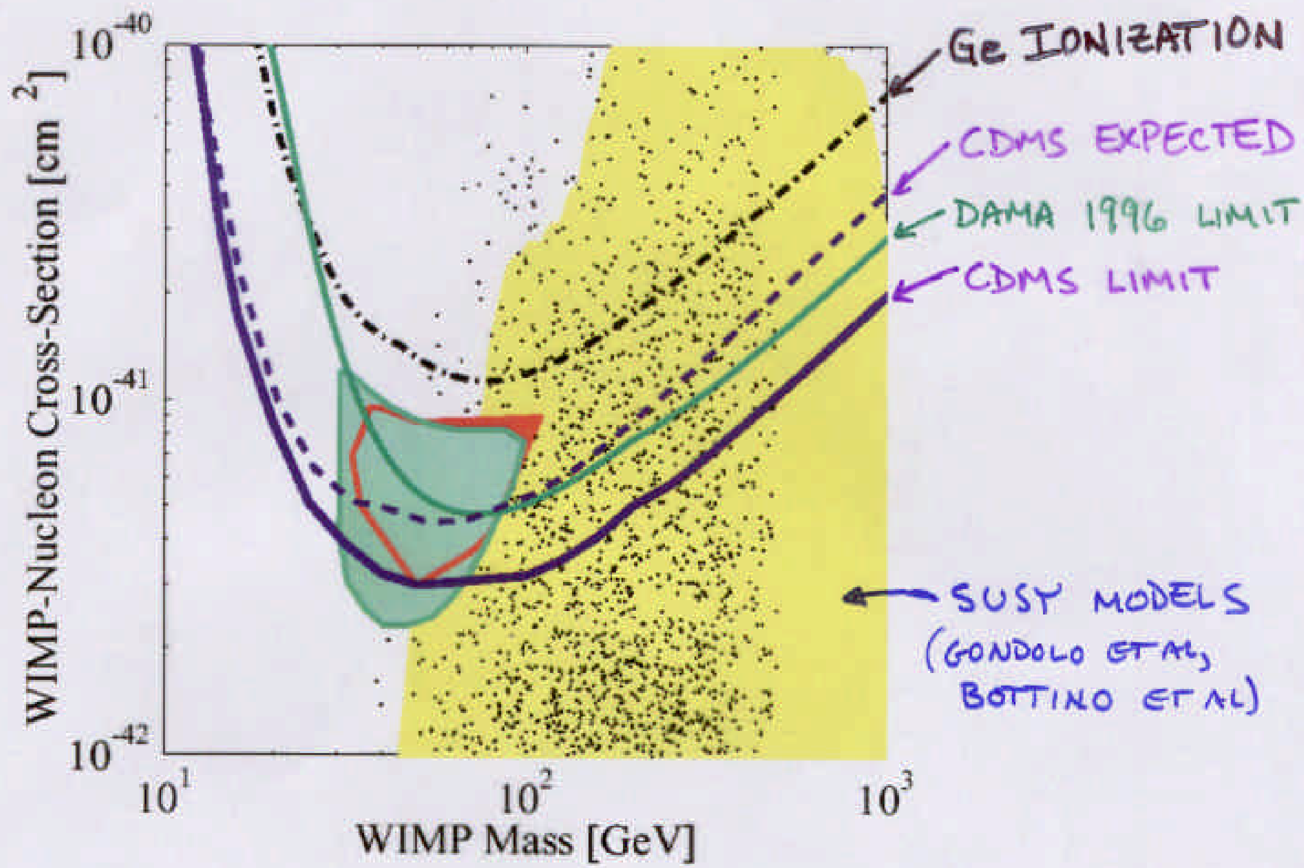
$\sigma_{\text{WIMP-NUCLEON}}$

M_{WIMP}

REJECT HYPOTHESES THAT FAIL 90% C.L. CUT

NEW CDMS LIMIT

- EXCLUDES NEW PARAMETER SPACE / SUSY MODELS
- BETTER THAN EXPECTED BASED ON Ge SINGLES SINCE MORE MULTIPLES (4 VS 1) BY 50%



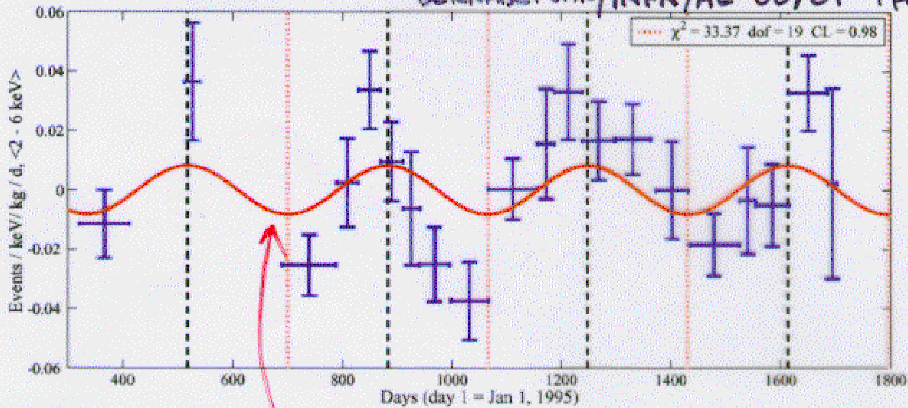
- BOTTOM OF DAMA NaI / 1-2 2σ CONTOUR EXCLUDED AT 89%
- BOTTOM OF DAMA NaI / 1-4 3σ CONTOUR EXCLUDED AT 75%

ACCEPTED FOR PUBLICATION IN PRL
SEE ALSO ASTRO-PH/0002471

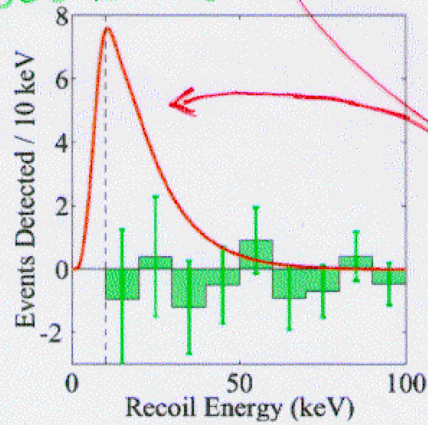
CDMS/DAMA COMPATIBILITY TEST

DAMA ANNUAL MODULATION DATA

BERNABEI ETAL/INFN/AE-00/01 1 FEB2000



CDMS AFTER SUBTRACTION



- ESTIMATE DAMA LIKELIHOOD FUNCTION
- COMBINED DAMA/CDMS LIKELIHOOD ⇒ BEST SIMULTANEOUS FIT A^2
- BEST FIT RULED OUT AT 99.7% CL

⇒ TOO SMALL MODULATION
TOO LARGE TOTAL RATE

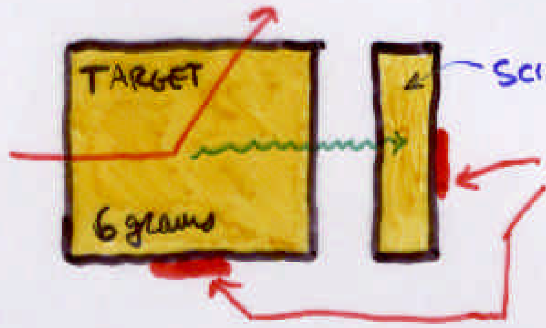
- IGNORE CDMS Si ⇒ STILL 99.7%
- IGNORE CDMS Ge MULTIPLES BUT INCLUDE Si ⇒ 97.5%
- USE CDMS "EXPECTED" ⇒ 97.5%

CRYOGENIC DETECTORS
(WITH RECOIL DISCRIMINATION)

CRESST (GRAN SASSO)

$CaWO_4$ → THERMAL : W SUPERCONDUCTING TRANSITION THERMOMETER

$CaWO_4$ → SCINTILLATION : SECOND CRYSTAL



98% γ REJECTION [10-20

NEXT: 300g

ALSO Al_2O_3 (THERMAL ONLY)

4x262 g 500eV THRESHOLD BACKGROUND SOLVED

IMPROVED RESULTS SOON.

EDELWEISS

Ge → THERMAL : NTD THERMISTORS

Ge → IONIZATION

99.6% γ REJECTION

98% SURFACE-BACKGROUNDS (β) REJECTION @ 50% EFFIC.

1997 DATA 1.17 kg·d 70g DEVICE

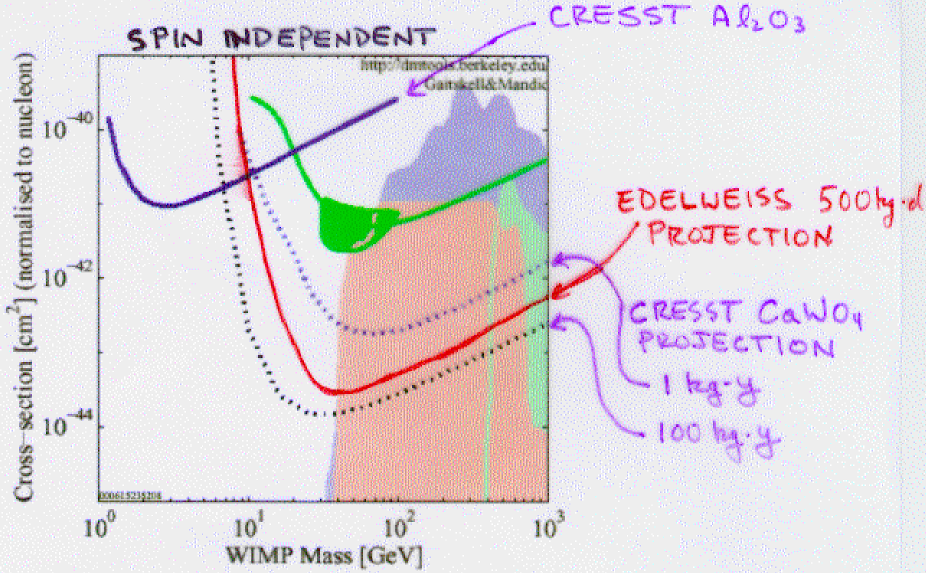
⇒ HIGH BACKGROUNDS

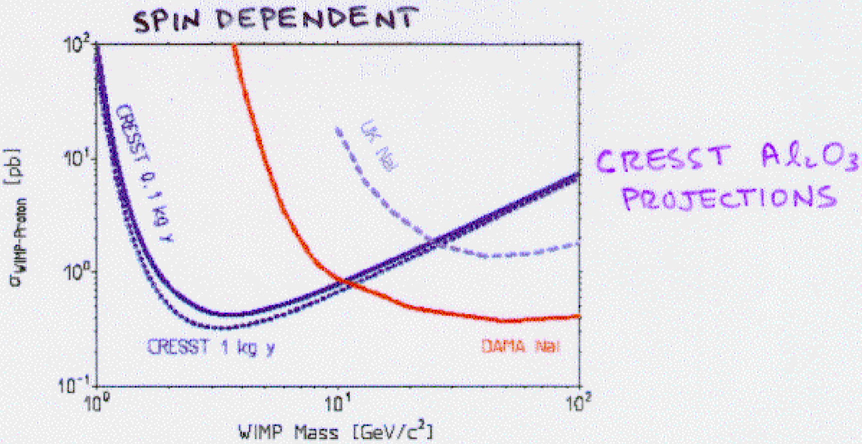
ADD NEW MEASURES (30cm NEUTRON MODERATOR, ROMAN LEAD, N_2 PURGE)

IMPROVED RESULTS SOON

NEXT: 1 kg TARGET MASS + ACTIVE VETO

CRYOGENIC LIMITS





CRYOGENIC LIMITS

DATA listed top to bottom on plot

- CRESST exclusion limit, 25/02/00
- DAMA 1996 Exclusion Region (90%CL)
- DAMA 2000 58k kg–days NaI Ann.Mod. 3sigma,w/o DAMA 1996 limit
- CRESST, projected 1 kg y $CaWO_4$
- CDMS, projected at Soudan mine ≈ CRESST 100 kg y $CaWO_4$
- Corsetti & Nath, mSUGRA predictions
- Gondolo et al. SUSY (Gaugino–like Models)
- Gondolo et al. SUSY (Higgsino–like Models)
- Gondolo et al. SUSY (Mixed Models)

000615235201

SCINTILLATION DETECTORS

- NaI, CaF_2
- LOWER QUENCHING FACTORS (I, Ca, F < 10%)
  LESS RADIOPURE, PMTs
- BUT:
  - LARGE MASSES (10 - 100 kg)
  - SENSITIVE ALSO TO SPIN-DEPENDENT COUPLINGS (^{23}Na, ^{127}I, ^{19}F)
  - RECOIL DISCRIMINATION → WIMPS, NEUTRONS: NUCLEAR; → γ, β : ELECTRON

⇒ FIRST TO SURPASS Ge IONIZATION

↓

UKDMC

1996: 6.2 kg NaI (BOULBY MINE)

PULSE-SHAPE DISCRIMINATION

4x IMPROVEMENT OVER THEN CURRENT S.I. Ge LIMITS

50x FOR S.D.

DAMA NaI ~ 100 kg

FURTHER IMPROVENTS → R. BERNABEI'S TALK

ELEGANT V

730 kg

HIGH BACKGROUNDS

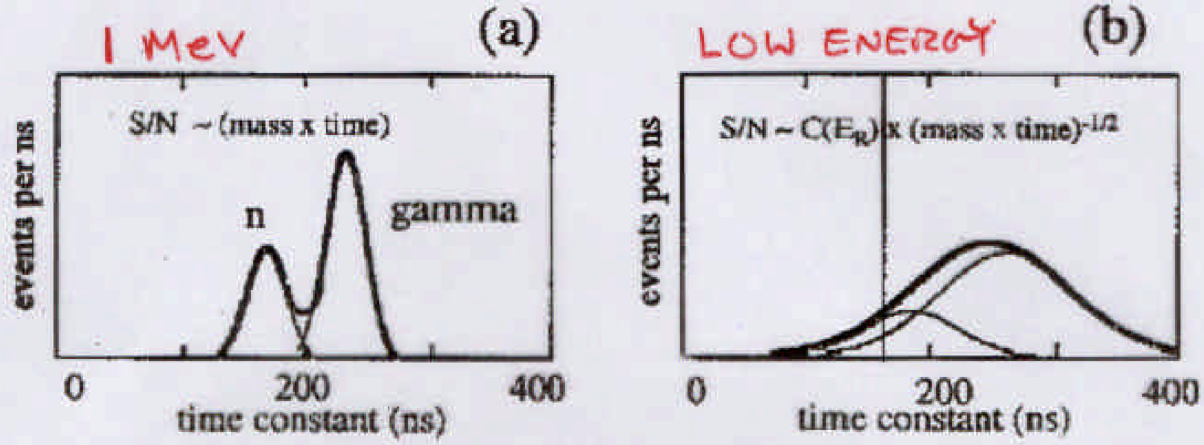
SACLAY

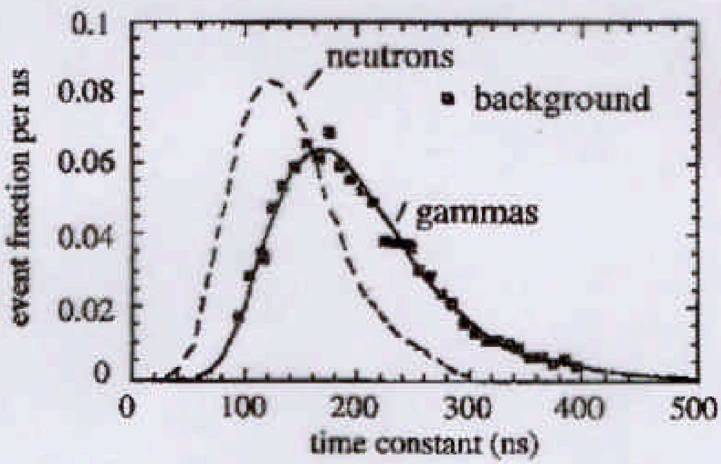
10 kg NaI

ANOMALOUS EVENTS
— SEEN BY UK, TOO...

PULSE SHAPE DISCRIMINATION — UKDMC

PULSE FALL TIME SENSITIVE TO RECOIL TYPE

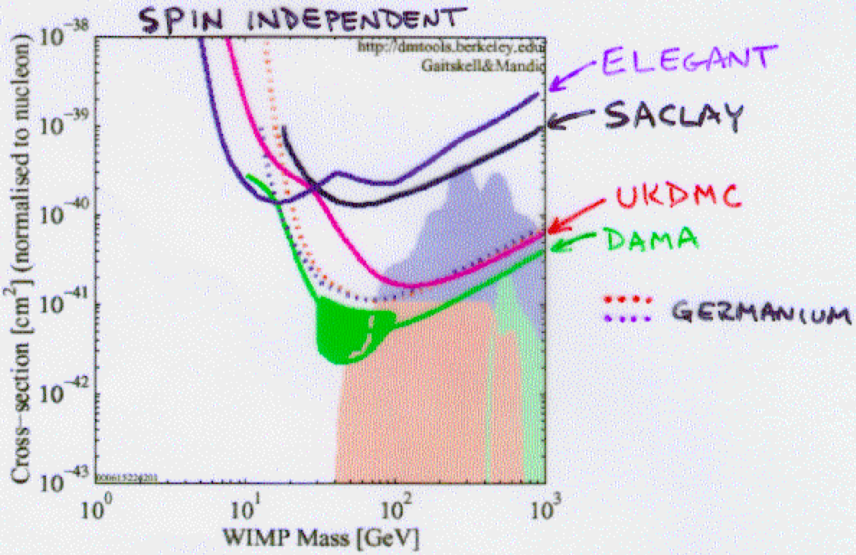


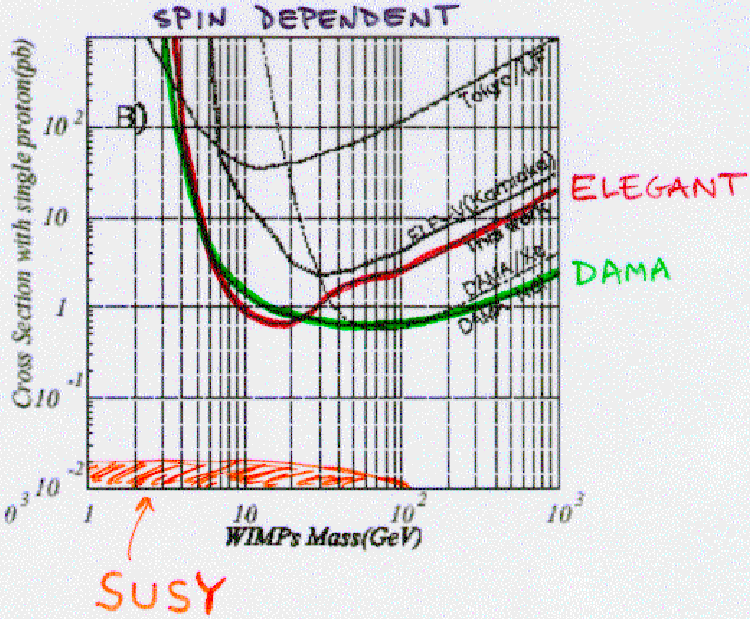


DATA FIT WELL BY THEORETICAL CURVE FOR GAMMAS.

PSD ALSO USED BY SACLAY, DAMA

SCINTILLATION LIMITS





Spin independent

DATA listed top to bottom on plot

- ELEGANT spin indep. limit, OTO COSMO Observatory
- Saclay exclusion limit
- UKDMC
- IGEX exclusion limit
- Heidelberg Moscow, 1998
- DAMA 1996 Exclusion Region (90%CL)
- DAMA 2000 58k kg–days NaI Ann.Mod. 3sigma,w/o DAMA 1996 limit
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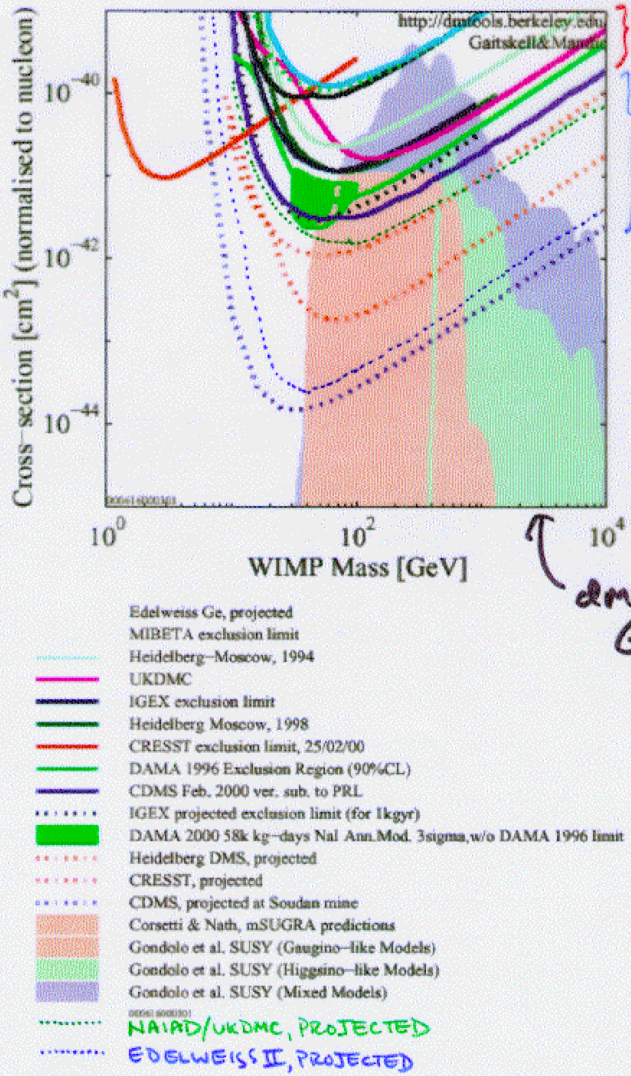
- Gondolo et al. SUSY (Mixed Models)

CONCLUSION

- RANGE OF MATERIALS / TECHNIQUES ⇒ SYSTEMATICS
- CONVENTIONAL DETECTORS
  - RADIOPURITY, eg, IGEX, ROSEBUD
  - NEW CONFIGURATIONS, eg, UK NaIAD
- CRYOGENIC DETECTORS
  - DISCRIMINATION, LOW THRESHOLDS



} MANY SUCCESFUL EXPERIMENTS 'TO DATE'

} PROJECTED SENSITIVITY WILL FURTHER TEST DAMA REGION AND MUCH MORE PARAMETER SPACE.

+ FURTHER DEVELOPMENTS

V. ZACEK

↑ dmtools.berkeley.edu GAITSKELL & MANDIC