Future Direct Dark Matter Experiments

V. Zacek, Université de Montréal

- Cryogenic detectors
- Ultrapure Ge
- LXe
- TPC approach
- Superheated liquids
- Superheated grains

Neutrino2000, Sudbury, June 2000

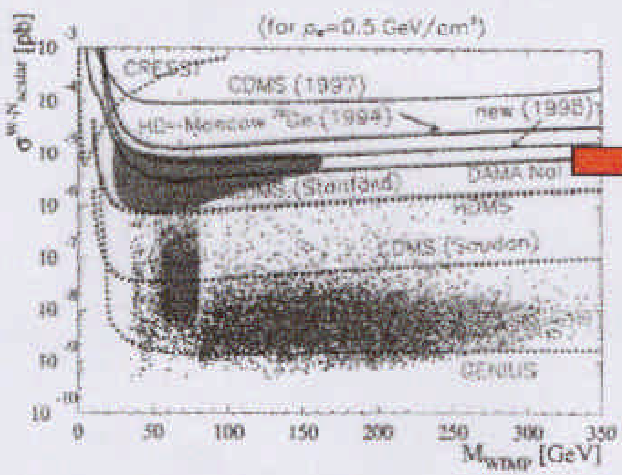
MOTIVATION

★ **DAMA result is an important benchmark for future experiments**

- **Check with different techniques & target materials**
- **...needs large active masses (10 - 100kg) →statistics**

★ **SUSY and mSUGRA give well understood predictions for neutralino DM and collider physics**

- **5 - 7 free parameters**
- **Neutralino DM rates < 1ct/kgd**
- **Scatter plot bounded at low DM cross sections**



Present experiments start to cut into parameter space !

(V. Klapdor et al. Eur. Phys. J.A3 (1998) 85)

★ **Also LHC covers all SUSY parameter space...**

- **....but DM search below 0.01cts/kgd more sensitive to large tanβ, where collider experiments appear more difficult**

(H. Baehr & M. Brhlik, Ringberg 1997)

Present Limitations of DM experiments

★ **Interesting range of sensitivity <1 ct/kg/d ; for recoil energies : E_{rec} ~10 keV and lower…**

However…

- **Detectors sensitive to α, β, γ radiation → good shielding, efficient γ-rejection and radiopurity required**
- **Neutrons difficult to discriminate**
- **Cosmogenic activation can be important source of intrinsic contamination**

Detector	Backgr. Supp.	Cts/kg/d 10…100keV	Mass
Ge	Purity	~ 10	~10 kg
NaI	Pulseshape	~ 1÷10	~100 kg
Cryogenic detectors	Ionization vs. Heat Scintillation	~ 1÷10	~ 400 g

In principle…

Exposure of few kgd with little or no background or a clear WIMP signature would be competitive…

Next generation of DM experiments

- How to improve a factor 100…1000… or more?

- Ideally needed:

  - “Background blind“ detector
  - exclusively sensitive to nuclear recoils
  - threshold below 10 keV
  - mass > 100 kg
  - low cost detector material

….challenging !

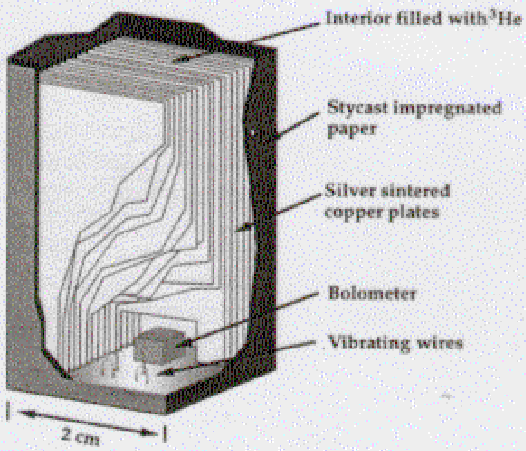
MACHe3

(CNRS/IN2P3 Grenoble)

★ Quasiparticle excitation & detection in superfluid ^{3}He

Detection principle:

- Small cubic cell of 0.123 cm^3 filled with ^{3}He in superfluid phase B in a larger cooling cell, connected by a small hole (Lancaster cell)
- Two vibrating wires in the cell are damped by quasi particle excitations produced by particle interaction
- 1 keV threshold at 100 μK demonstrated in prototype



Background rejection:

- High purity of ^{3}He
- Matrix configuration → correlations among cells
- high n-cross section allows to tag n-background

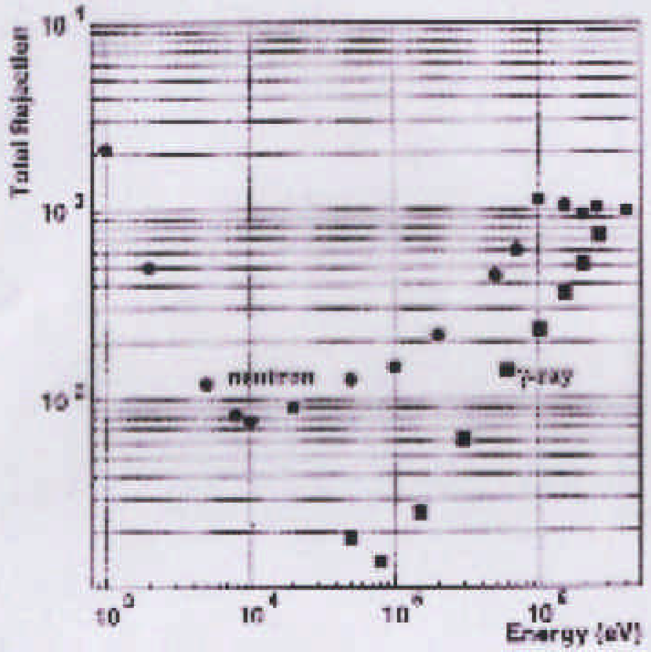
$n + {}^3He \rightarrow p + {}^3H + 764$ keV for $E_n < 10$ KeV

Status:

- So far measurement with one cell
- Detailed simulations of matrix of 1000 cells, 1cm wide each

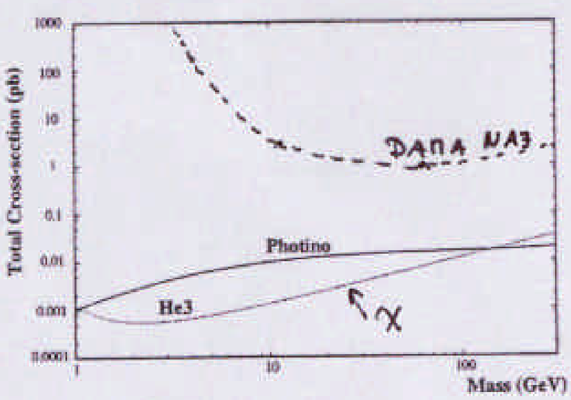
MACHe3

Background rejection:



excellent n/γ rejection !

Projected limits:



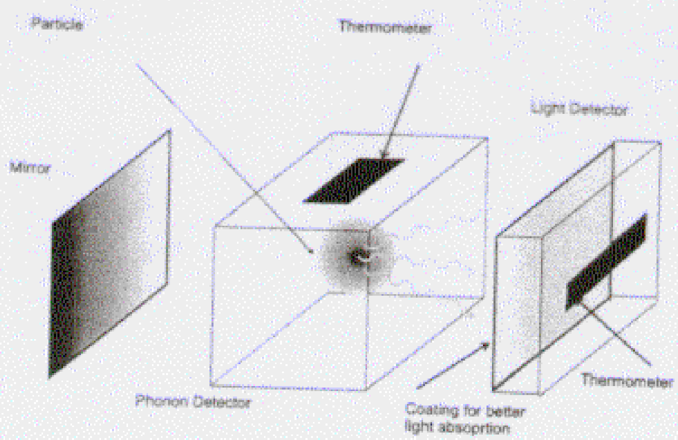
Spin-dependent cross section with 10kg active mass of ^3He

CRESST (MPI, TUM, Oxford, LSNGS, JIN)

★ **Cryogenic calorimeter with transition edge thermometer read out (+…upgrade)**

Detection principle:

- **300g modules of $CaWO_4$ ($\sigma_{coh} \propto A^2$!!) as scintillating WIMP target**
- **simultaneous detection of phonons & scint. photons (λ=400nm)**
- **phonons by W transitione edge therm. $\rightarrow E_{th} \approx 15$ keV**
- **photons detected in μm SiO film on Sapphire/W bolometer detector surrounded by 4π mirror (3M)$\rightarrow E_{th} \approx 50$eV**
- **operation at 12 mK**

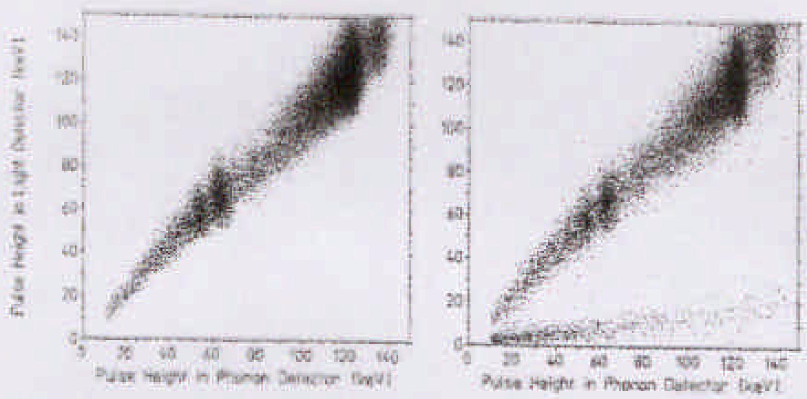


- **prove of principle with 6g detector**

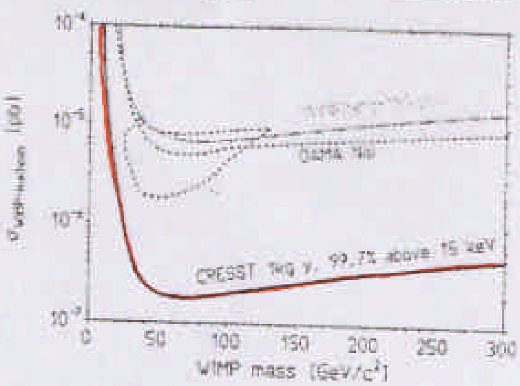
CRESST

Backgound suppression:

- response with electron, photon and ^{241}Am n-source
- Leakage of electron recoils into nuclear recoils determines discrimination power → 99.7% rejection of el. rec. possible
- intrinsic contamination low



Limits: ...set up permits installation of 100kg target



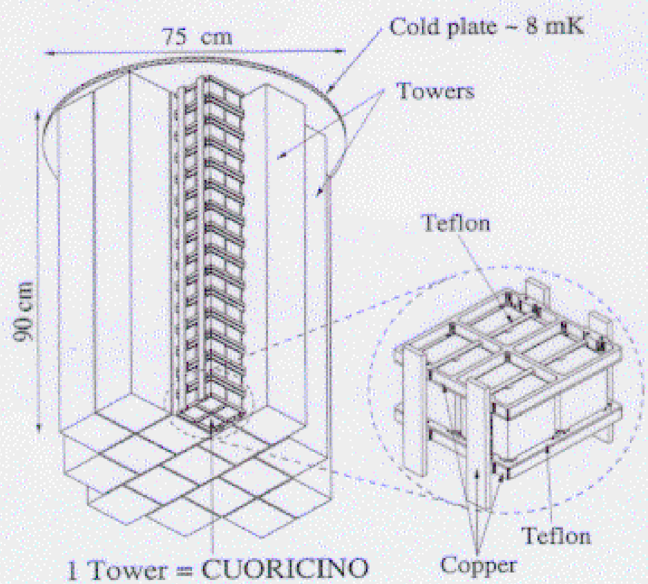
- coherent interaction: 1kg y @ 99.7% rejection...

CUORE/CUORICINO (Milano, LNGS, Neuchâtel)

★ Cryogenic bolometer

Detection principle:

- Array of ~1000 TeO_2 bolometers with 750g mass each (crystal size 5 x 5 x 5 cm^3)
- Crystals arranged in towers; 1 tower → Cuoricino



Background reduction:

- 2 thermistors on one absorber→greater S/N for stoch. Noise and rejection of non-thermal events
- 3cm Pb inside cryostate

Status:

- one plane results (4 cryst.): FWHM@46.5keV=1±0.15keV !
- R/O with cold electronics → $E_{th} \approx 4 \div 5$ keV
- Crystals polished against surface contamination
- Installation @ LNGS

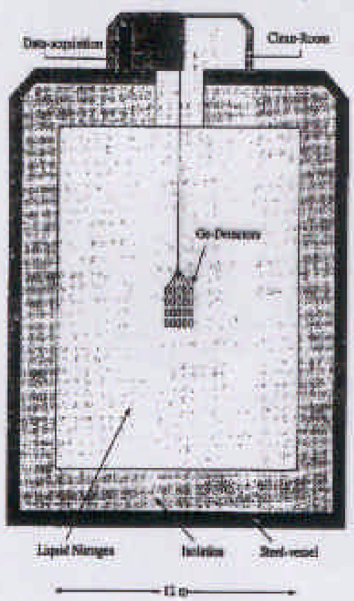
GENIUS / ~~GENINO~~ GENIETTO

Heidelberg/Kiev/PTB/Trieste/Dubna/Novgorod/Boston/ Maryland/Valencia/Texas

★ **Ultra high purity natural Ge-crystals in LN_2**

Detection principle:

- **LN_2 can be produced very clean**
- **Removement of all dangerous contaminations**
- **Shielding from external activity**



Background reduction:

- **about a factor 10^4-10^5**

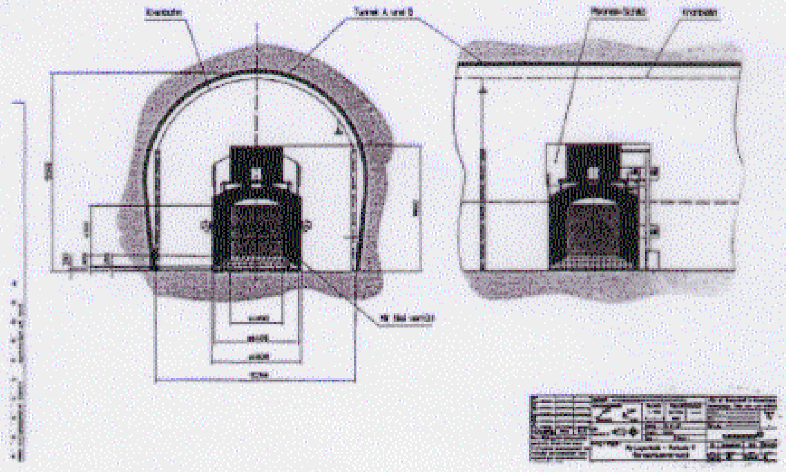
GE~~NINO~~: GENIETTO

- **Study of feasibilty with smaller set-up but same target mass of 100kg nat. Ge.**
- **part of LN_2 replaced by Pb**
- **min LN_2 tank 5m diam. Pb ≈ 25cm**

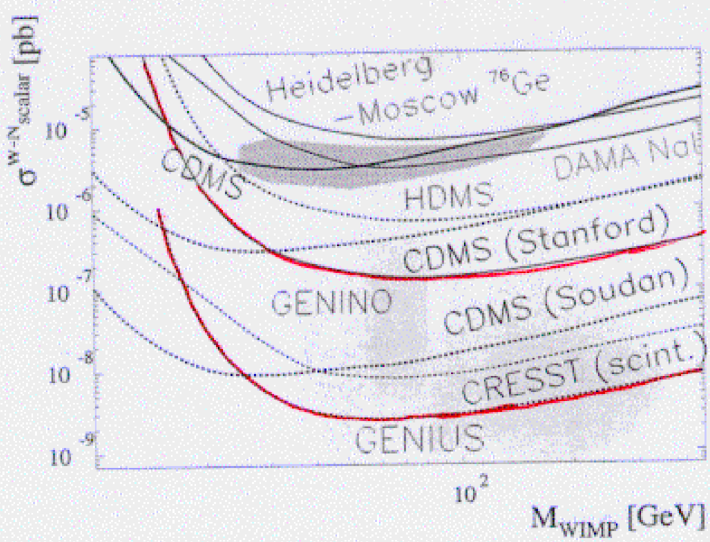
Status: **Background simulations; experience from HDMS…**

GENIUS/~~GENINO~~ GENIETTO

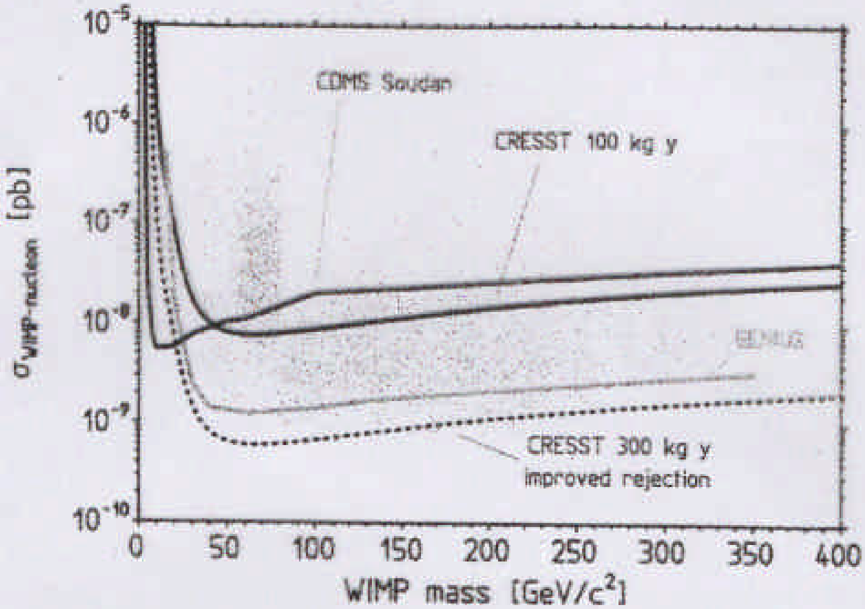
Installation (LNGS):



Expected Limits:



CDMS / CRESST / GENIUS….



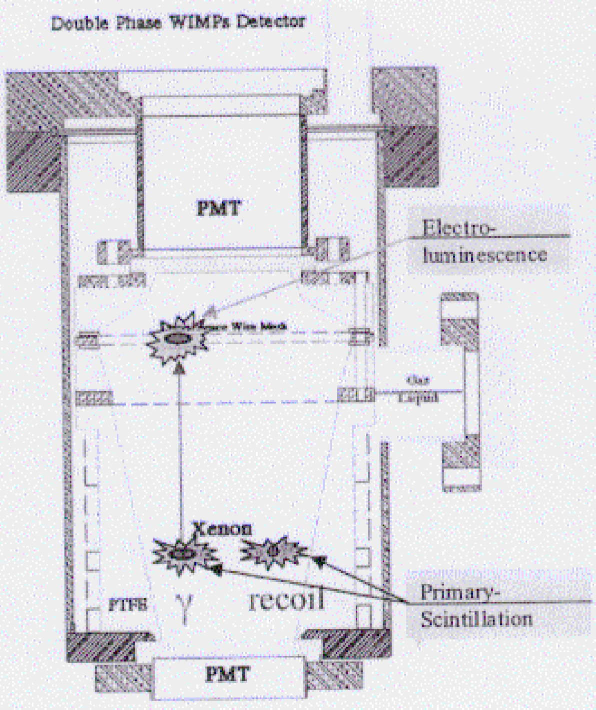
ZEPLIN II

(RAL, Sheffield, ICSTM, ITEP, Torino, UCLA)

★ Two-phase Xe- detector

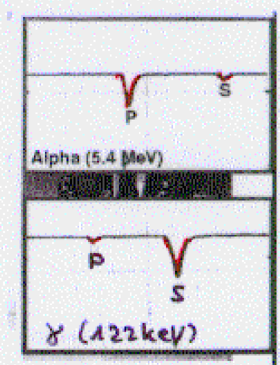
Detection principle:

- **Xe-recoils (E_{rec}<10 keV) produce scintillation and ionization**
- **primary ionization e^- drift towards LXe surface**
- **e^- extracted in vapor phase and accelerated in strong E-field**
- **excitation of $Xe^* \rightarrow$ deexcitation $\rightarrow$ electroluminescence**



Background rejection:

- **Proportions of SC and EL different for e,γ and recoils**
- **discrimination by factor 10^3-10^4 !**

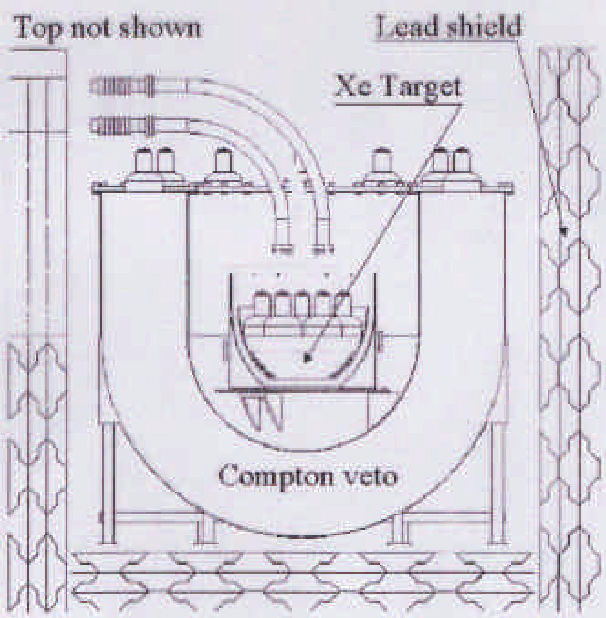


ZEPLIN II

Status:

- **High ionization and light yield @175 nm (→purity)**
- **Recoil threshold < 10keV**
- **Development of internal CsI photocathode (→red. backg.)**

Shielding Setup



Future:

- **with a 30 kg Zeplin detector ($Z=54$, $\rho=3g/cm^3$) most of the SUSY region will be covered after 1 year running**
- **Installation in Boulby mine**

CDM TPC (Temple, Occidental, UKDM)

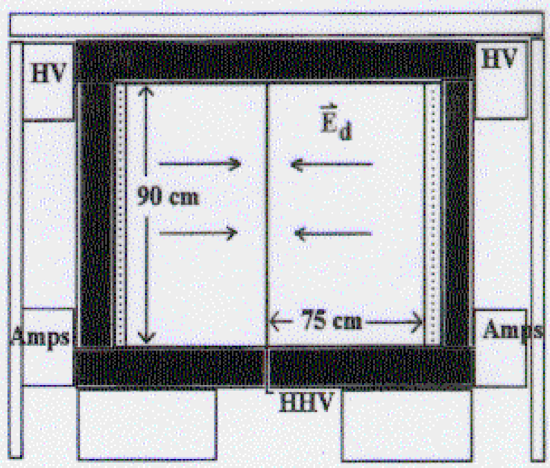
★ High resolution TPC (Rich & Spiro 87, Elliott et al. $\beta\beta 2\nu$)

Detection principle:

- measure range, ionization, track characteristics & direction
- segmentation in 3D; determine fiducial region in gas
- ordinary TPC: w/o B-fld degradation in position resolution
- Drift negative ions → transverse and longit. diffusion stay small → no magnet required; 1 m drift length possible; work at 40 Torr

Background rejection:

- 10^{-5} misident. prob. for 13 keV e^-
- $5*10^{-2}$ misident. α



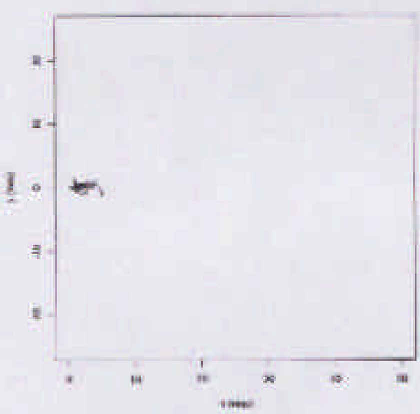
Limits:

- 1 year running; $1m^3$; 40 Torr → 36 kgY → 10 x DAMA

CDM TPC

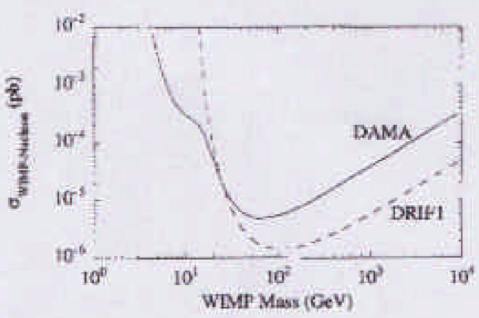
Event discrimination:

13 keV e⁻ in 40 Torr Ar



40 keV Ar in 40 Torr Ar

Exclusion plot for 36 kg years exposure:



PICASSO (Université de Montréal)

★ Superheated droplet detector (SDD)

Detection principle:

- For a given superheat (P_{vap}-P_{ext}) a critical amount of energy E_c has to be deposited within a radius R_c (→ bubble chbr.)
- Nuclear recoils with dE/dx > 200keV/µm trigger phase transition → γ, β, µ don't.
- 50-100 µm droplets suspended in polymerized gels; collaboration with BTI Deep River, Ont. (→n-counters)
- rupture of metastability detected with piezoelectric sensors
- threshold as low as 10 keV (depends on temperature)

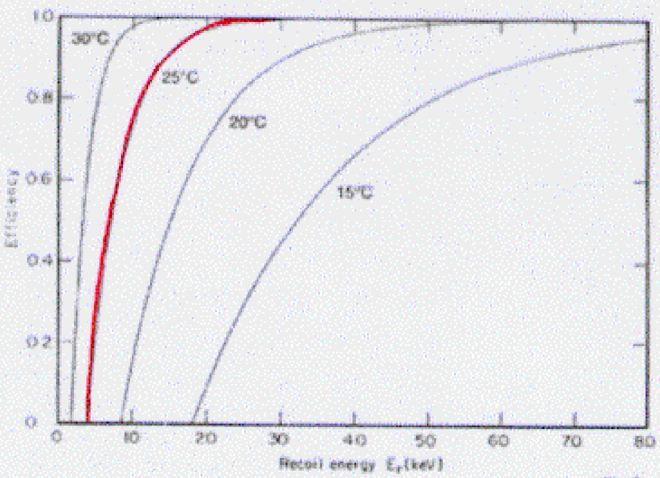


Fig. 2

SDD's are threshold counters!

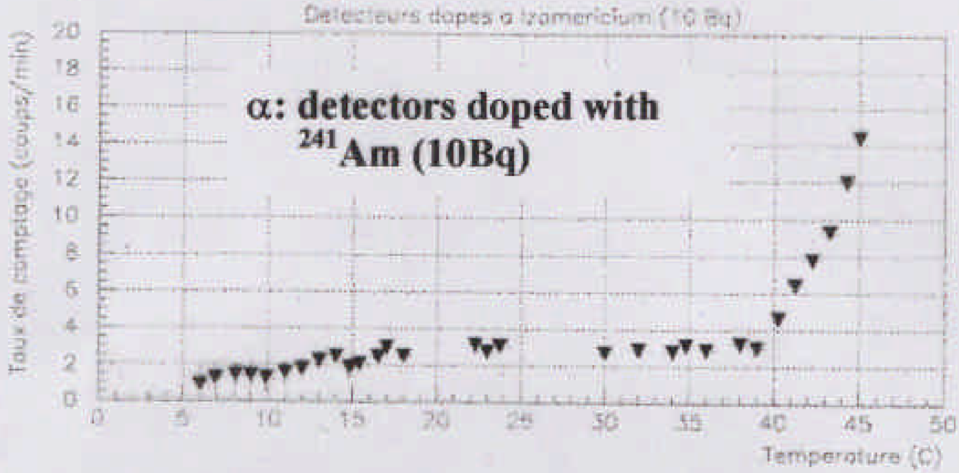
spectral info by ramping the temperature!

- Liquids: C_4F_{10}, C_3F_8, $CBrF_3$…operate at ambient T & P → already quite clean and… cheap (~60$CD/kg)
- Fluorine rich→largest spin dependent cross section

PICASSO

Status:

- **Systematic study of detector response**



γ, x-rays: ^{60}Co and ^{55}Fe

Sensitivity reduced by ~ 10^7 at room temperature

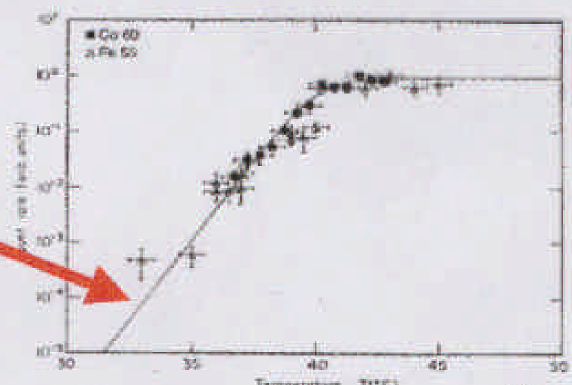


Fig. 6

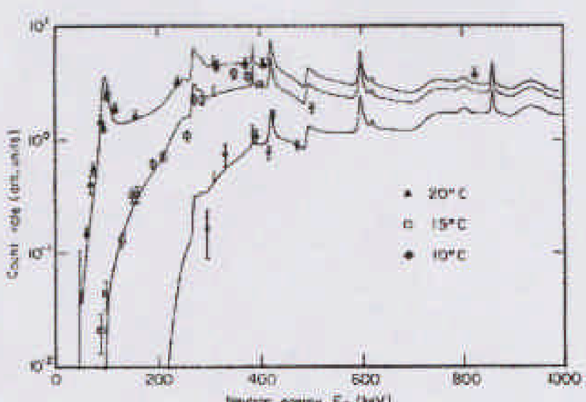


Fig. 1

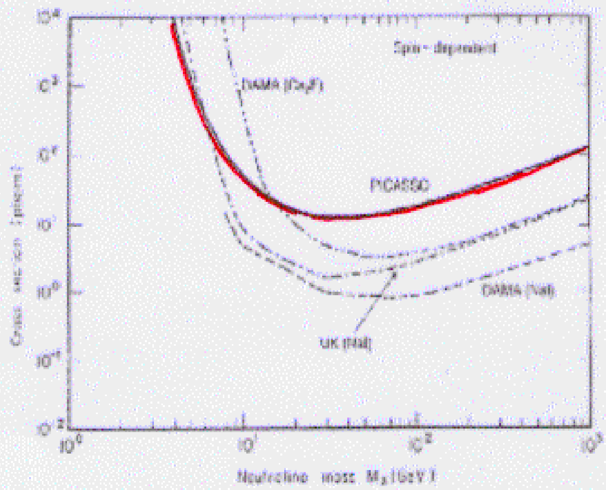
neutrons with UdeM tandem

SDD's at ambient temp. only sensitive to α and neutrons

PICASSO

First limits on spin dependent interaction

- set of 16 detectors with 0.7% loading→ 1.34g active mass
- installation in Montréal lab; 5m gravel + Mont Royal
- 1.5t water shield + N_2-flushing
- data at two thresholds: 54.7d @10keV; 41.7d @60keV



Sensitivity:
220±210cts/kg/day

Despite of very small exposure of 0.06kgd already good limits due to high ^{19}F content+low backg.

Future:

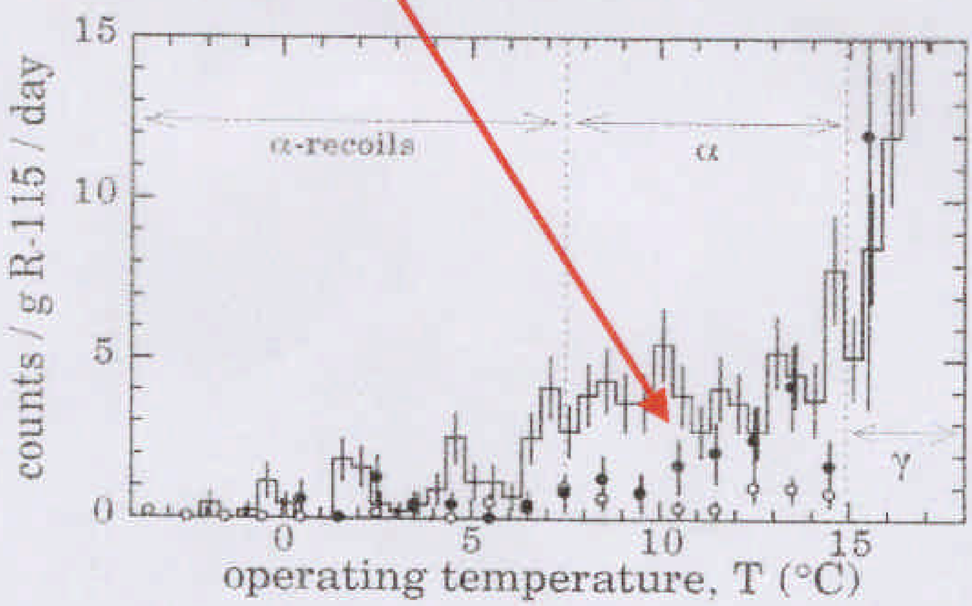
- Summer '00: installation of 100g module → 20cts/kgd
- Work on U/Th purification: 20cts/kgd→ 0.2cts/kgd
- Summer '01: installation of 1kg; → 0.06cts/kgd ??

SIMPLE (Paris, Lisbonne, Pacific Northwest)

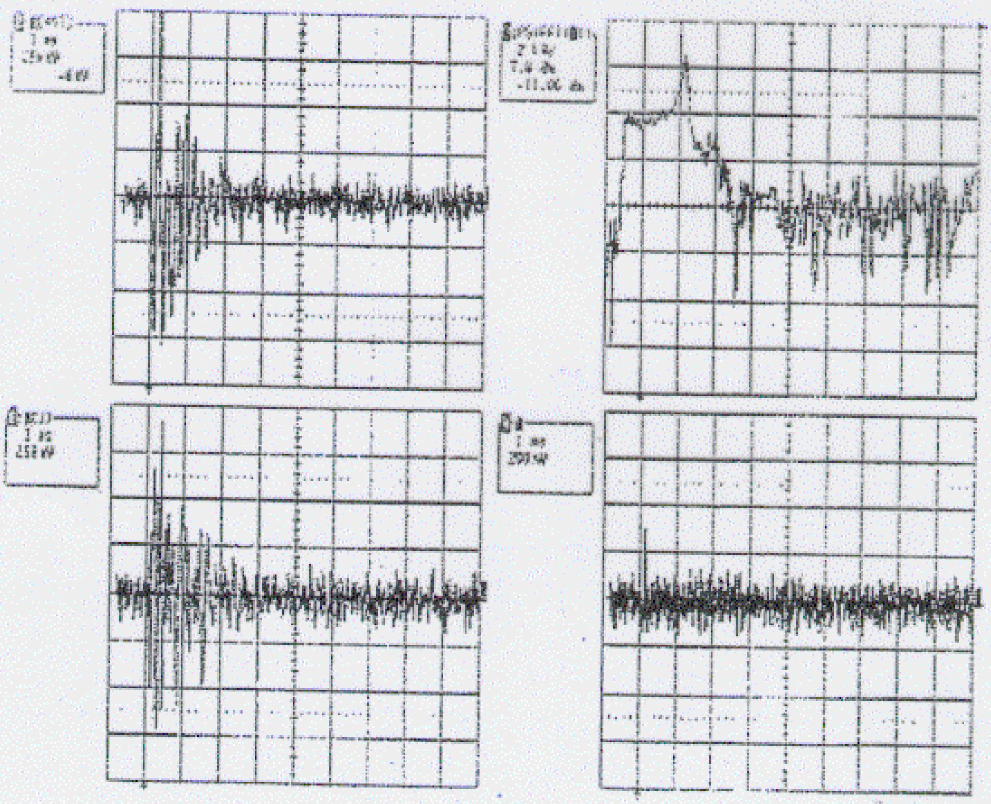
★ Superheated Droplet Detector

Status:

- **Study of α-response with ^{241}Am spiked detectors**
- **^{252}Cf neutrons, MC –simulation reproduces n-spectra**
- **reproducible production of 15g modules (< 10$US) in pressure reactor → C_2ClF_5**
- **cumulative purification; 2 distill., microfiltration, resins..**



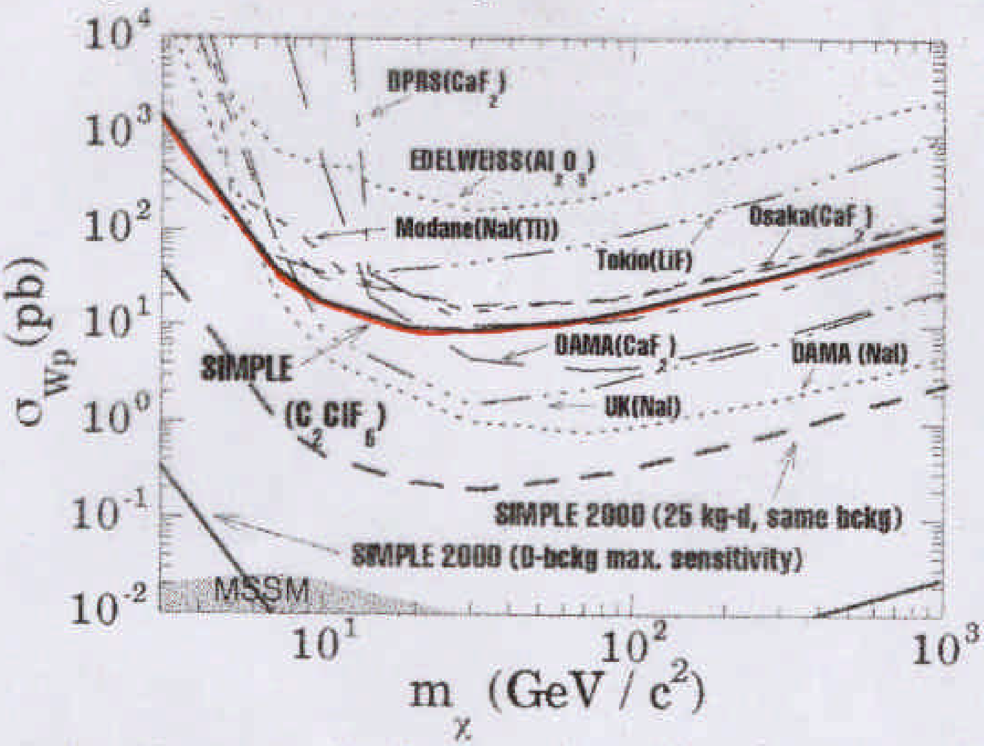
Signals & noise:



SIMPLE

First limits on spin dependent interaction

- Installation in new Rustrel-Pays d'Apt (~1500m.w.e.) Labo.
- Module of 9.2g C_2ClF_5 installed in thermally regulated water bath, surrounded by 700l water moderator
- Temp. ramping up/down for 44 days (→energy spectrum)
- Integrated countrate ~250cts/kgFd above 3.2 keV
- Origin of dominant background microleaks in SDD cap



Future:

- This year ('00) installation of 8-16 modules→25 kgd
- Monochromatic n-calibration with filtered reactor neutrons
- Tests of $CBrF_3$ modules

ORPHEUS (BERN / PSI / ANNECY)

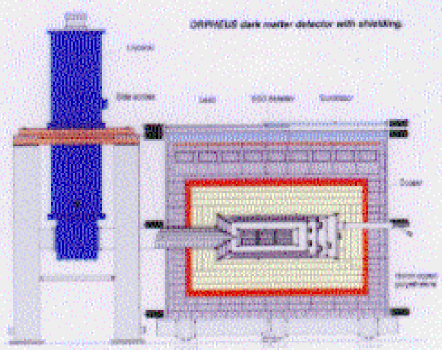
★ Superheated Superconducting Granule Detector

Detection principle:

- μ-sized, type-I superconductor spheres in dielectric filling material
- particle interaction triggers phase transition from metastable superconducting to normal state
- transition sensed with magnetic Meissner-effect
- threshold ≈1 keV

Background rejection:

- γ/recoil discrim. by number of flipped granules; single flip → WIMP signal.



Status:

- Recoil sensitivity proven with 70MeV n-beam (PSI)
- Start 1kg SSG detector
- Cold box installed
- Working on Squid read-out

Conclusions

- Remarkable progress in detection techniques during last years
- Experiments are about to reach sensitivity to probe large regions of neutralino DM SUSY parameter space
- ...or study with high precision annual modulations
- apologies to:

  DAMA, EDELWEISS, ELEGANT, CDMS, CASPAR, UKDMC, ROSEBUD, HERON, COSME...

....all heading for increased sensitivity, larger mass and improved background rejection → details in proceedings