Dark Matter Searches

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The Astrophysics Puzzle

- Non baryonic hints
- MACHOs

What Can Particle Physics Offer?

- Axions
- Light Massive Neutrinos
- WIMPs

Direct Detection of WIMPs

- Current status and strategies
- DAMA
- CDMS
- Outlook

Indirect Detection of WIMPs

Dark Matter and Dark energy

Existence: Solid evidence for Dark Matter => Consensus

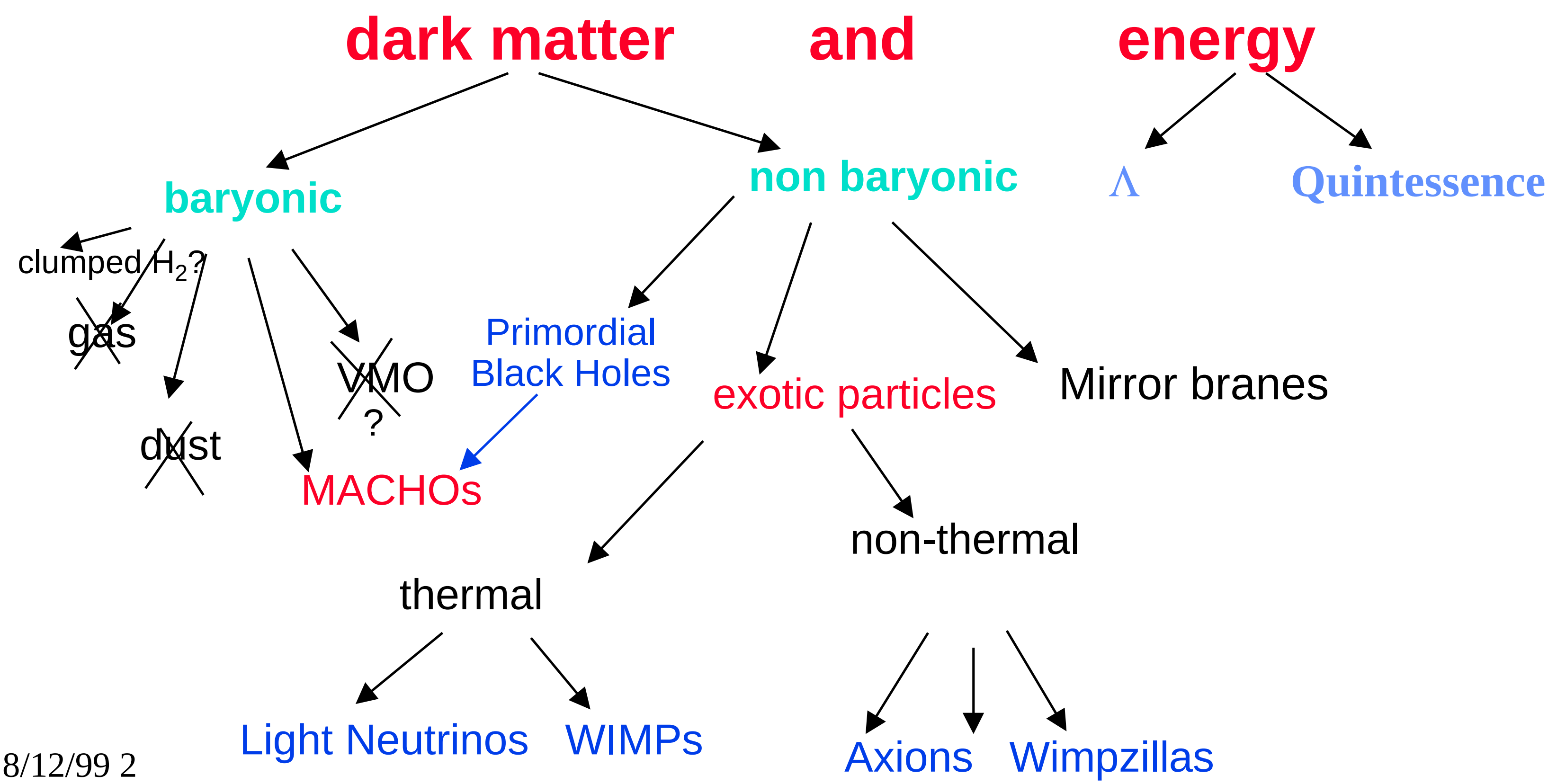
Rotation curves in spiral galaxies

Globular clusters/ gas around elliptical galaxies

Velocity dispersion in clusters
X-ray gas in clusters
Gravitational lensing by clusters

Same depth of potential wells

Nature? Systematic effort to map possibilities



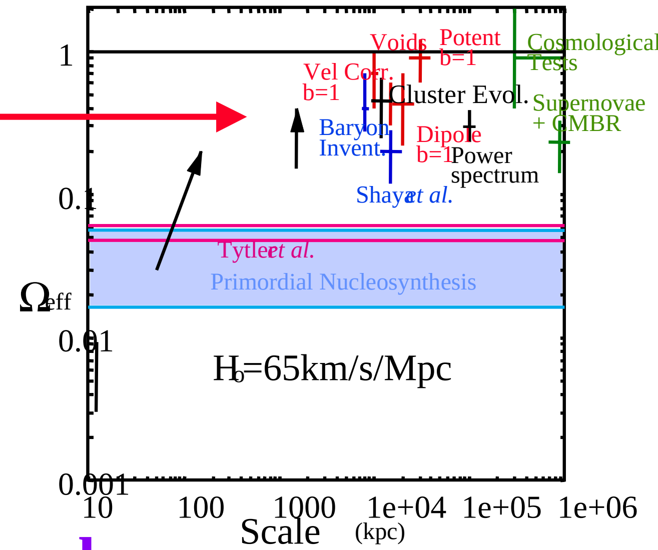
Indications for non-baryonic nature

a)Effective Ω vs. Ω

Ω appears to be much higher than conventional primordial nucleosynthesis

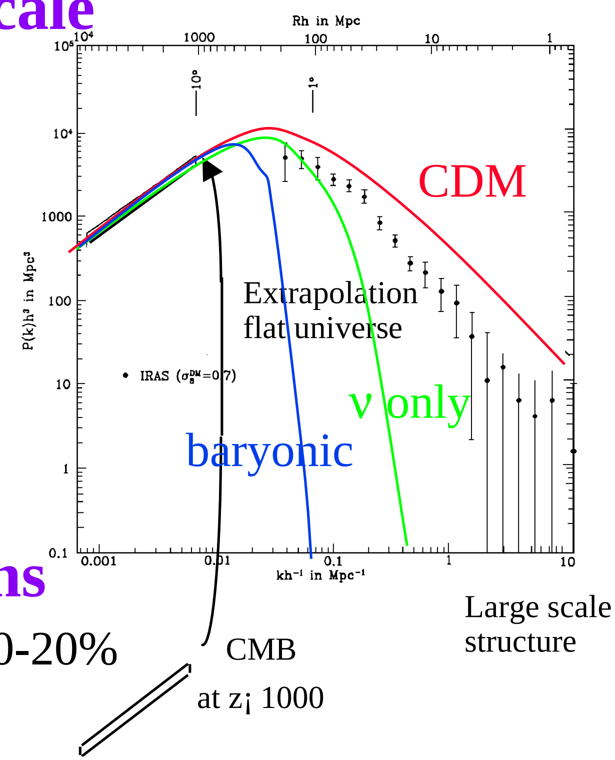
Not undermined by recent cosmic microwave background + Supernova results (systematics?)

Independent of Inflation!



b)Comparison of CMB ΔT/T and large scale

Order of magnitude of ΔT/T is natural with non baryonic dark matter and adiabatic fluctuations!



c) Implausible efficiency of hiding baryons

e.g. Baryonic content of clusters: Baryon fraction 10-20%

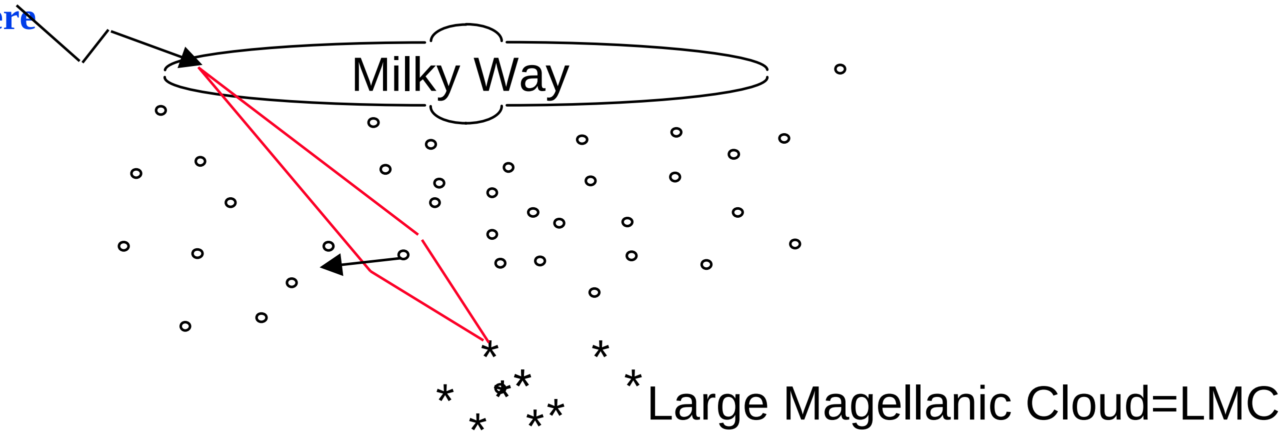
Would have to hide >80% baryons in MACHOs

MACHOs

Massive Compact Halo Objects

The basic idea

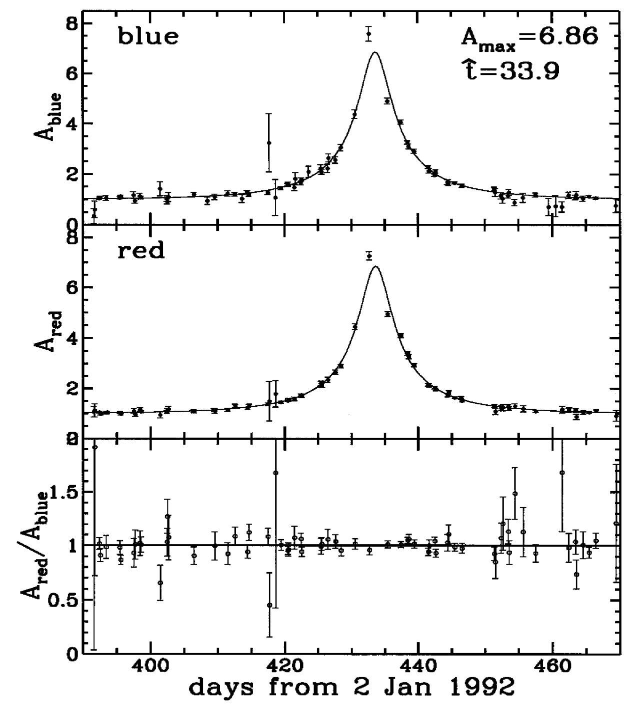
you are here



3 main collaborations

CfPA MACHO, EROS, OGLE + new groups and M31

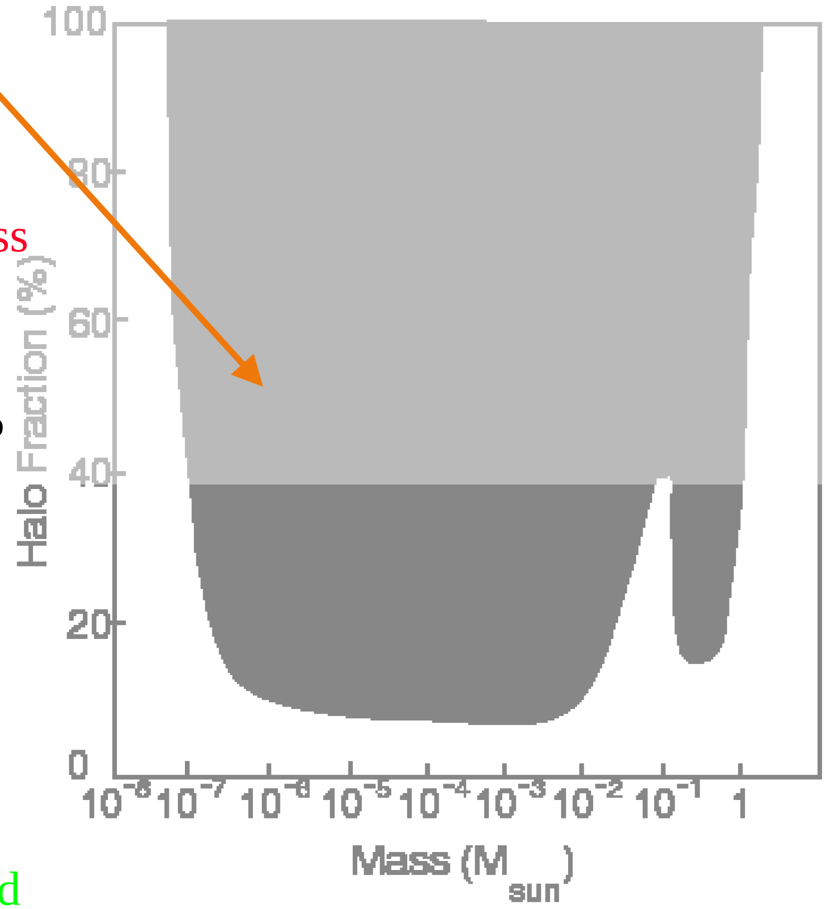
Clear demonstration of microlensing



MACHOs

No small LMC/SMC duration events

=> Dark Matter Brown Dwarfs



Puzzling long duration LMC events

- Degeneracy between velocity,distance and mass

  We do not know where the lenses are!
- Even if distributed as halo:

  MACHO Group result: 10%¡ fraction¡ 100%

  Serious difficulties with "natural" conclusion

  that it forms 100% of halo

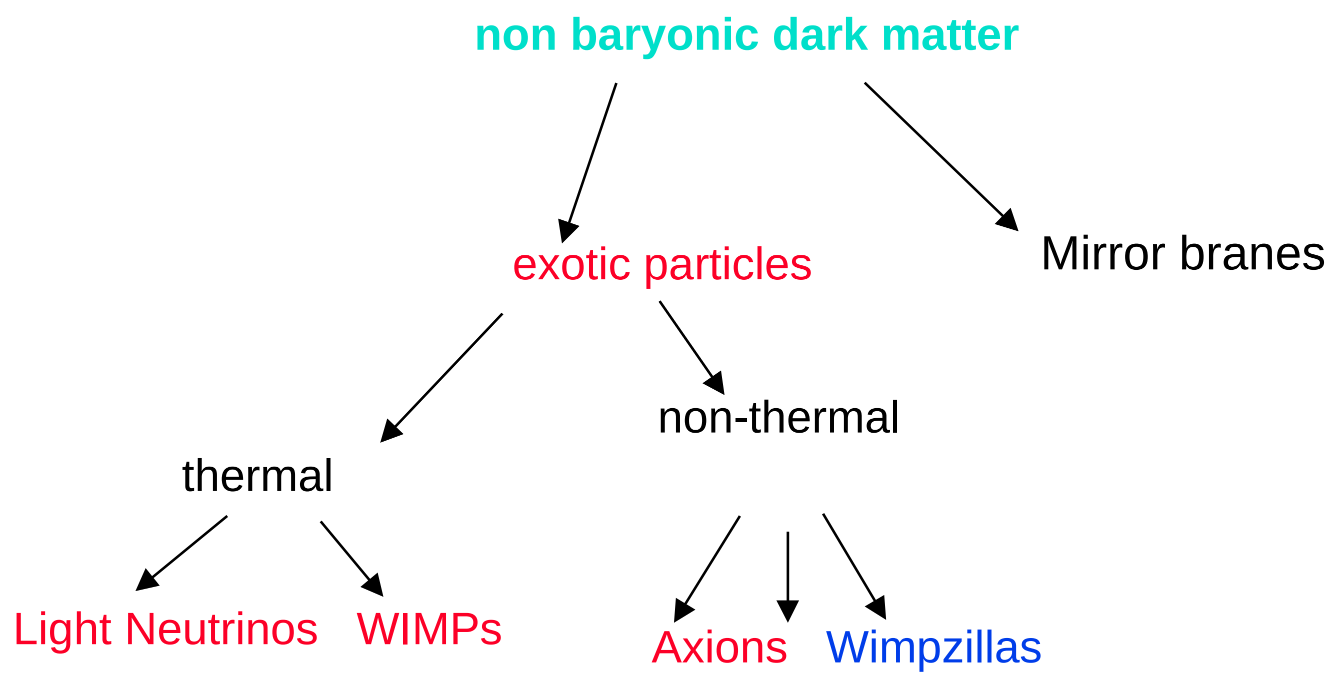
  how to hide O.5 Msun objects?

  how to build a self consistent cosmology?
- The few lenses whose positions are known are in the host galaxies, not in the halo!
- Not enough events (2) towards SMC
- My best bet: puffed up Large Magellanic Cloud

  <= tidal interactions with the Milky Way

2nd generation: **EROS II, OGLE II, SuperMachos + Stellar Interferometric Mission**

What can Particle Physics Offer?



Axions

Invented to save QCD from strong CP violation

Current experimental limits are such that if they exist, they have to be cosmologically significant

Window: 10^{-6}-10^{-3} eV

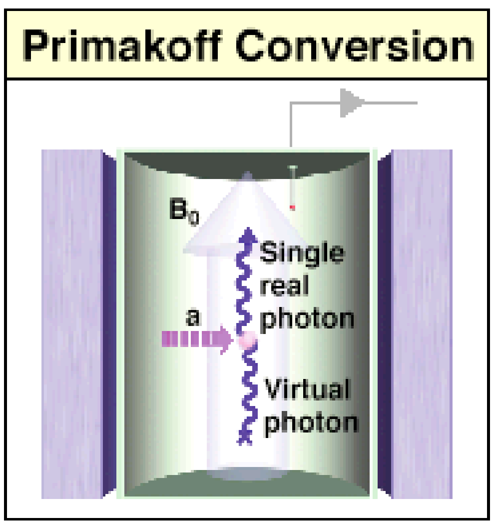
Produced out of equilibrium

Theoretical discussion if Peccei Quinnn symmetry breaking occurs after inflation

=> global strings which radiate axions. Technically difficult to compute (Shellard Sikivie)

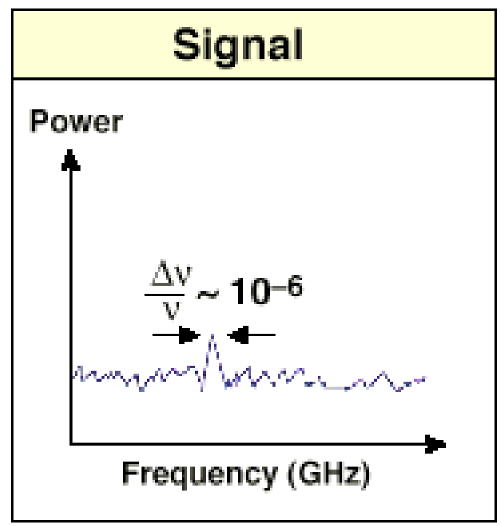
Loss mass region may be not favored

Method of detection



Tunable cavity

Most suitable for low mass region



Axions

After 2 pilot experiments missing sensitivity

The US axion experiment

Livermore–MIT–UC Berkeley/LBNL

– U. Florida –U. Chicago/FNAL

–INR Moscow experiment

First data analyzed, published, PRL 98

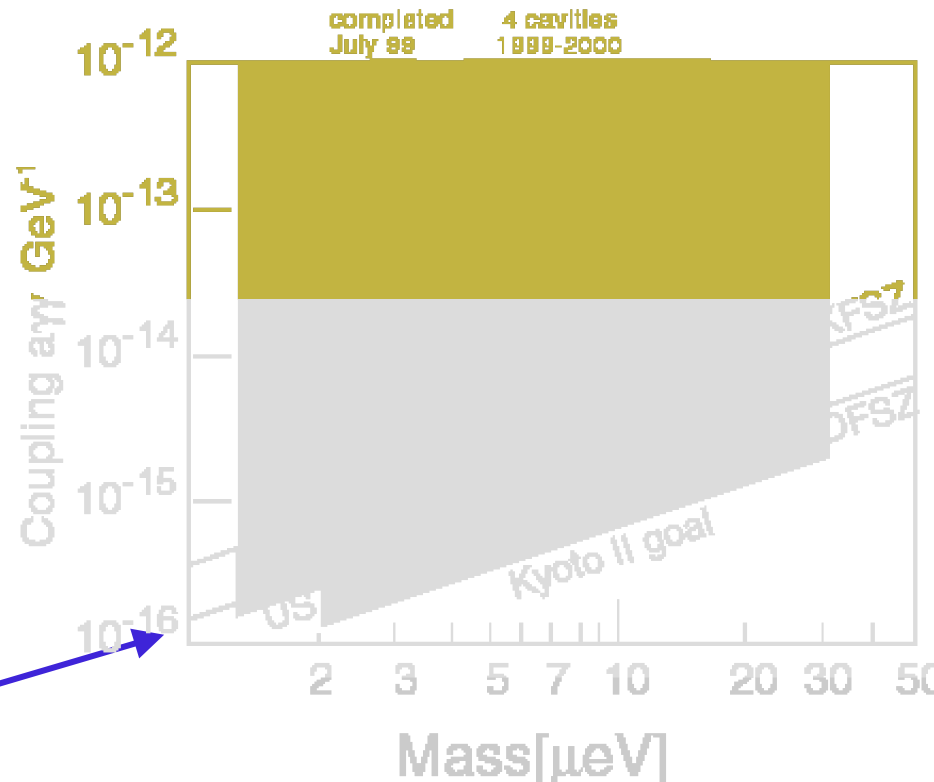
demonstrated sensitivity to KSVZ axions

Currently scanning wider region

R&D on DC SQUID amplifiers

underway at Berkeley

=> proposed upgrade reaching DFZS



Kyoto experiment

Matsuki et al. (Rydberg atoms)

Starting in narrow region but high sensitivity

These experiments reach a cosmological sensitivity!

Potential Problem: one decade out three mass decades allowed

Light Massive Neutrinos

Thermal equilibrium in early universe

+ *Decoupling when relativistic*

number ¡ number of photons
density <-> mass
40 eV /c² => Ω¡ 1

Cosmology

Cannot form galaxy alone:

- mixed dark matter
- seeding by topological defects

+ dwarf galaxy halos too dense for neutrinos

Experimental tools

Direct measurement of cosmological neutrinos appears impossible

=> laboratory mass experiments:

Tritium $M_{\nu e}$<5eV
Double beta decay $M_{Majorana\ \nu e}$<1eV
Oscillation experiments (LSND, Karmen , CHORUS, NOMAD, Chooz, Palo Verde,atmospheric and solar neutrinos)

Neutrinos are a small mass

Confirmation of ν_μ->ν_τ or ν_s oscillation by SuperKamiokande

Δm^2 taken at face value=> Density of cosmological neutrinos at minimum density of stars

Neutrino mass also hinted by for solar neutrinos

But no evidence for eV mass scale (if we reserve judgment on LNSD)

Weakly Interactive Massive Particles

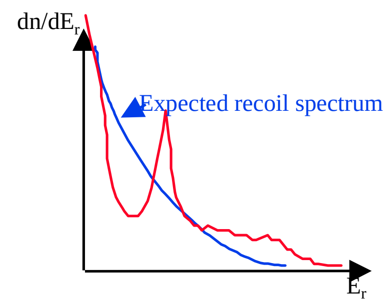
Particles in thermal equilibrium

+ decoupling when nonrelativistic

Density ~ 1/(interaction rate)
Ω ¡ 1 => σv ¡ 10^{-26} cm^3/s
Generic Class

Cosmology points to W&Z scale
Inversely standard particle model requires new physics at this scale
(e.g. supersymmetry) => significant amount of dark matter
We have to investigate this convergence!

Detection methods



- Elastic scattering : Direct detection
  - Expected event rates are low (<< radioactive background)
  - Small energy deposition (¡ few keV)

Signal = nuclear recoil
Background = electron recoil **(if no neutrons)**

- Indirect detection of annihilation products
  - Photon lines GLAST
    VERITAS/HESS if density cusp at the galactic center (controversial)
  - Antiprotons, positrons AMS (but confinement time)
  - Neutrinos from annihilation in sun or earth (atmospheric neutrinos)
    Current generation ¡ 1000m^2: MACRO-Baksan-SuperK
    -> km^3 array

Direct Detection: Current Status

Very active field

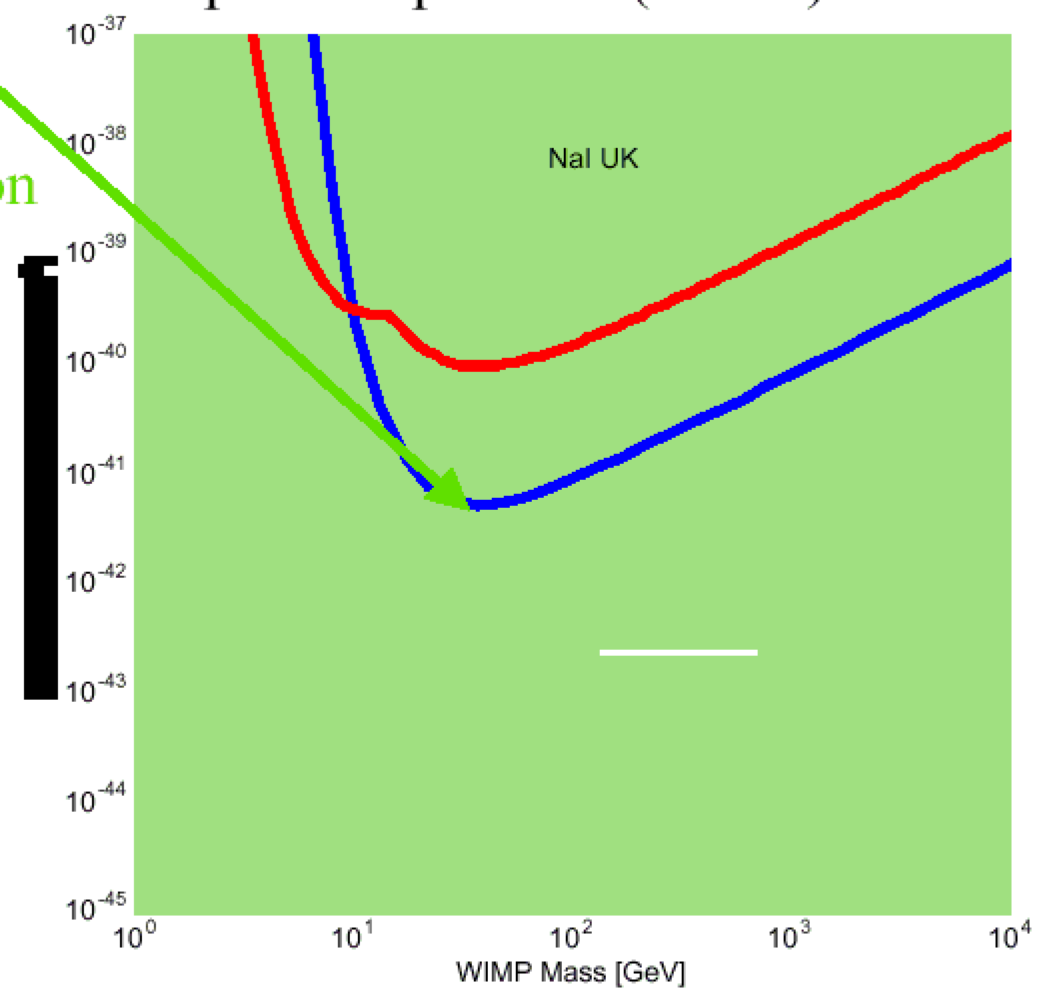
- Ge diodes (1989: USC/PNL, UCSB/LBNL)

  -> Heidelberg/Moscow = most reliable limit at large mass

- Large NaI counters (100 kg installed in Gran Sasso!)

Spin Independent (Scalar)

NaI ¡ 3σ claim based on annual modulation



Background limited

=>Effective mass is small

mass of background-less detector giving same limit

2.5 evt./kg/day

$(MT)_{eff}$=1kg.day

- Cryogenic detectors: CDMS starting to test DAMA claim

Gets into Minimum Supersymmetry territory!

Direct Detection: Background Strategy

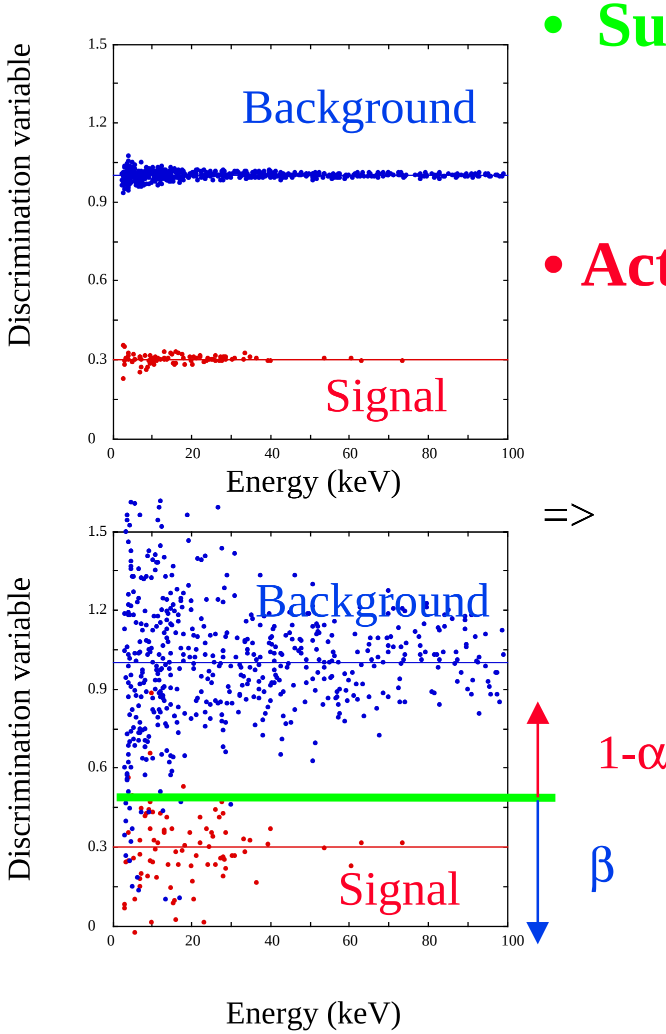
- **Decrease background:** ultra low radioactivity technology

However when background appears, no more progress!

- **Subtract background**

  Independent estimation of background by fit or Monte Carlo not reliable

  Yearly modulation but beware of systematics!



- **Actively reject background:**

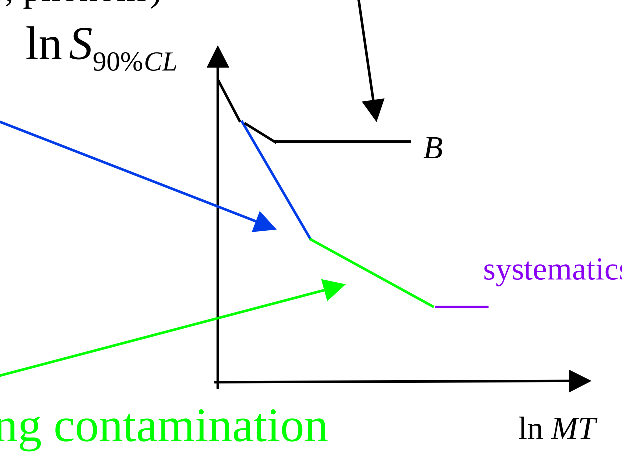
  Multiple scattering (small enough detectors)

  Deposited energy density (microdots, low pressure TP)

  Signal pulse shape (scintillators)

  > 2 measurements (ionization, photons, phonons)

=> Further decrease background



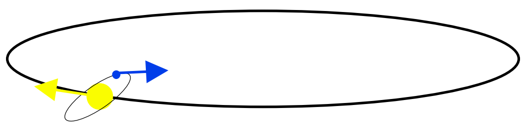
Measure and subtract remaining contamination

Till limited by systematics

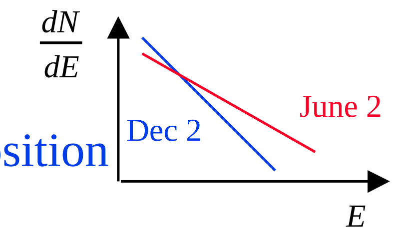
=> need best discrimination technique

DAMA and Annual Modulation

Basic idea

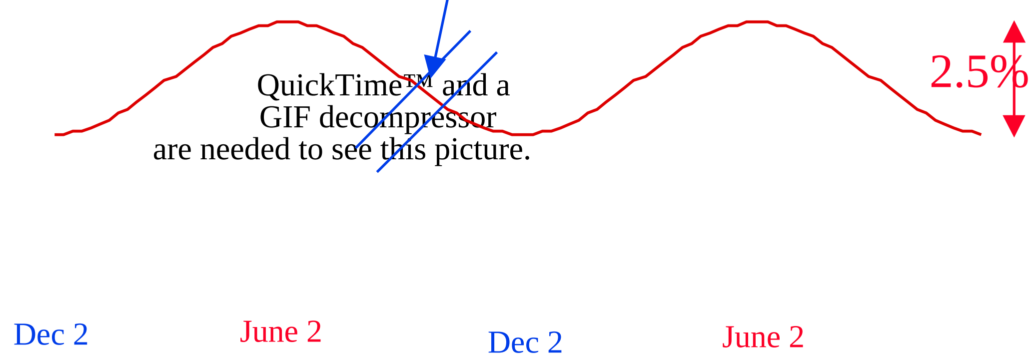


Wimp wind ¡ isotropic in halo frame ¡ 270km/s
Sun goes through this cloud at 220km/s
Earth adds or subtract 15km/s to sun velocity
=> ±4.5% modulation in rate, energy deposition



DAMA claim: 2 measurement campaigns (but set-up change prevents comparison)

19511 kg days
2.86σ = 99.6% CL
Goodness of fit =7.4% CL
- No systematics found with right phase
- (but what about lags?)



Difficulties

- No continuous observation of signal over at least one full period
  - A random drift could explain effect + phase is locked
- Claimed efficiencies appear unphysical
- No argument for required stability of detection efficiency close to threshold
  - Need better than 1% stability

Discrimination in Cryogenic Detectors

Principle: Phonon mediated detectors

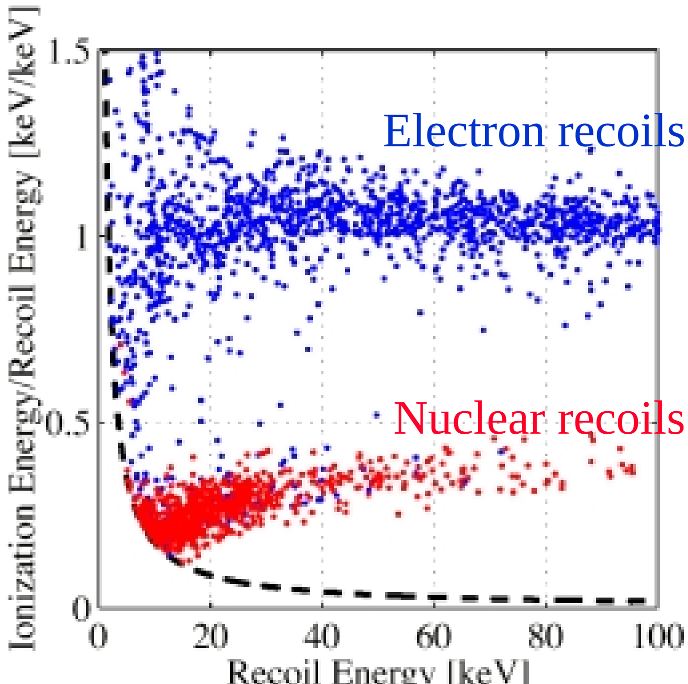
Simultaneous ionization measurement in Ge or Si (CRESST Photons in $CaWO_4$)

Advantages

- Sensitivity down to low energy

  Phonons measure the full energy (no ionization yield, quenching factor)
- Active rejection of background: recognition of nuclear recoil
- Maximum amount of information on rare events <= non equilibrium phonons: x-y position, surface

165 g Ge thermal detector at 20mK (CDMS)



Similar results with athermal phonons

The CDMS Experience

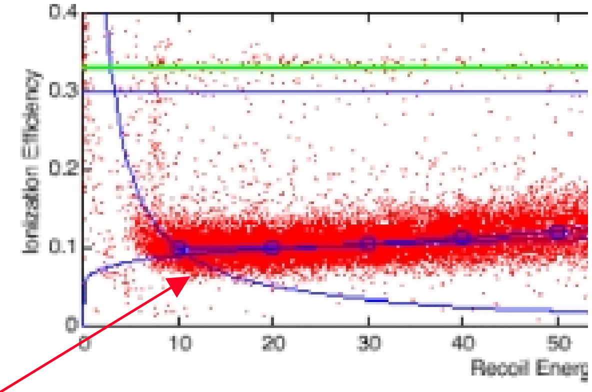
Approach

"A background can hide another one!"

Ionization (Ge,Si) + phonons(thermal and athermal)
Careful radioactivity control but shallow site (μ->n)

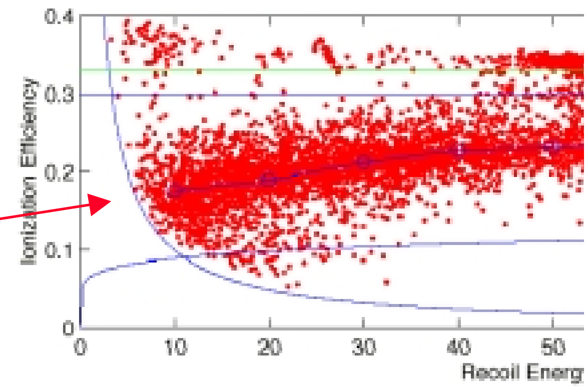
A running experiment

Since 1996 Excellent threshold and rejection >99% above 15GeV
Good gamma background (¡ 1/kg/keV/day before rejection)
1kg now installed



But Surface Electrons

Carrier back diffusion : ionization loss mimic nuclear recoil

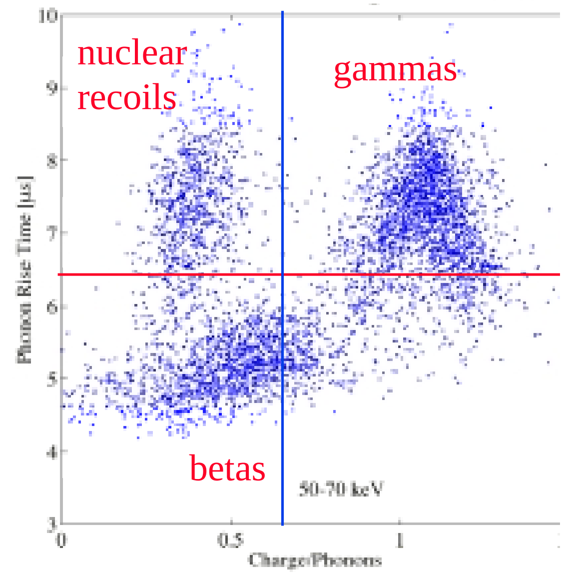


Corrective action

Better contacts | essentially all surface electrons eliminated
Close packing | => **Unfortunately neutrons!**
Cleaning | **But able to test DAMA**

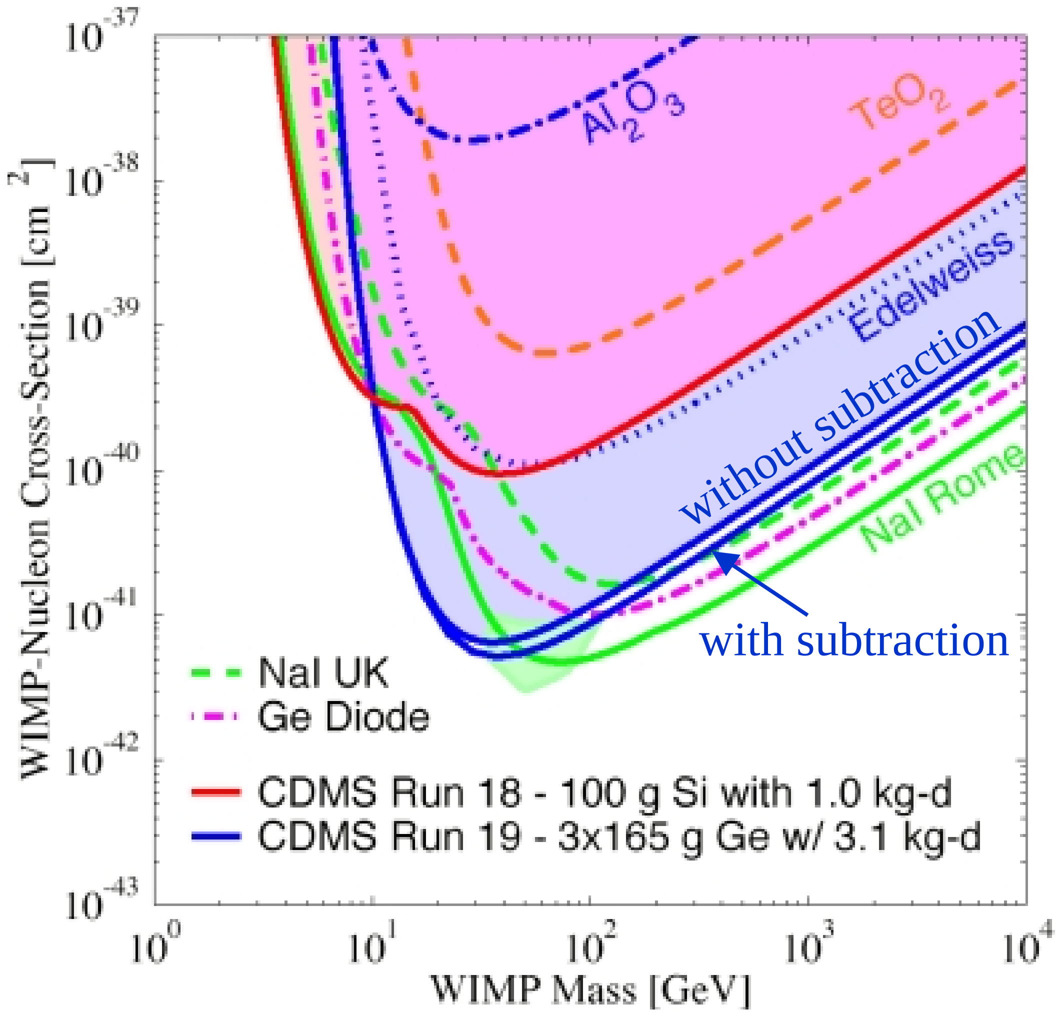
Athermal phonons provide another dimension

Interactions close to surface give faster pulses
Demonstrated on Si and now Ge. Compatibility with good contact
=> get closer to a background free experiment



CDMS Results

Exclude half of DAMA claim region



Current run: x 4 in statistics => full exploration of DAMA claim

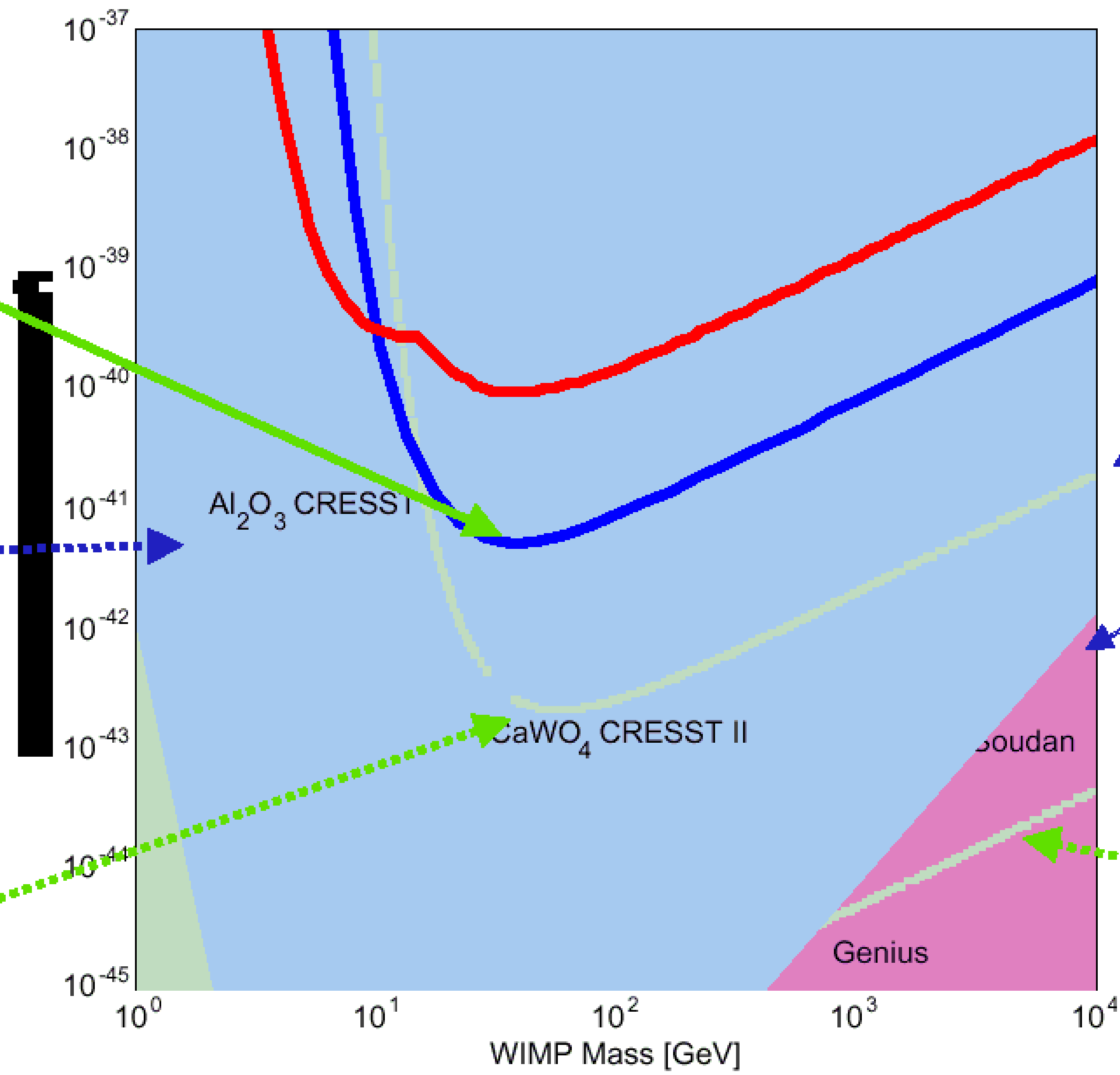
CDMSII deep underground: in final stage of review by DOE/NSF

WIMPS Direct Detection: an Outlook

NaI
systematic limited??

CRESST I
Background problem

CRESST II
Technology has to be extrapolated from 2.6g to 1kg



2.5 evt./kg/day
$(MT)_{eff}$=1kg.day

0.3 evt./kg/day
$(MT)_{eff}$=8kg.day

0.01 evt./kg/day
$(MT)_{eff}$=230kg.day

GENIUS
No rejection
Requires 10^4 improvement in background levels

+so far relatively untested ideas: liquid Xe
low pressure TPC

Direct-Indirect Comparison

Neutrinos from annihilation in sun or earth

With current generation of neutrino arrays ($10^4 m^2$):

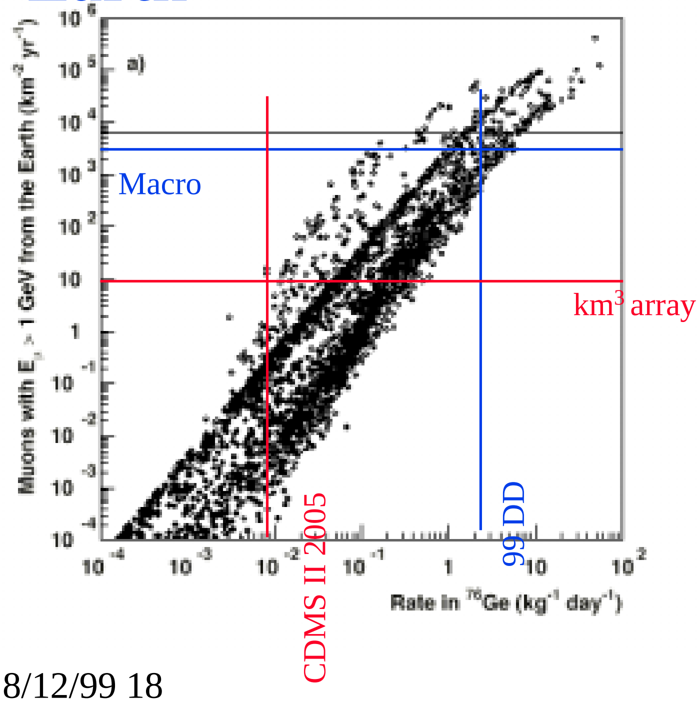
Limits MACRO/Baksan: few 10^{-14} μ's /cm^2 /s > 3Gev

About similar to DAMA/ Current direct detection experiments

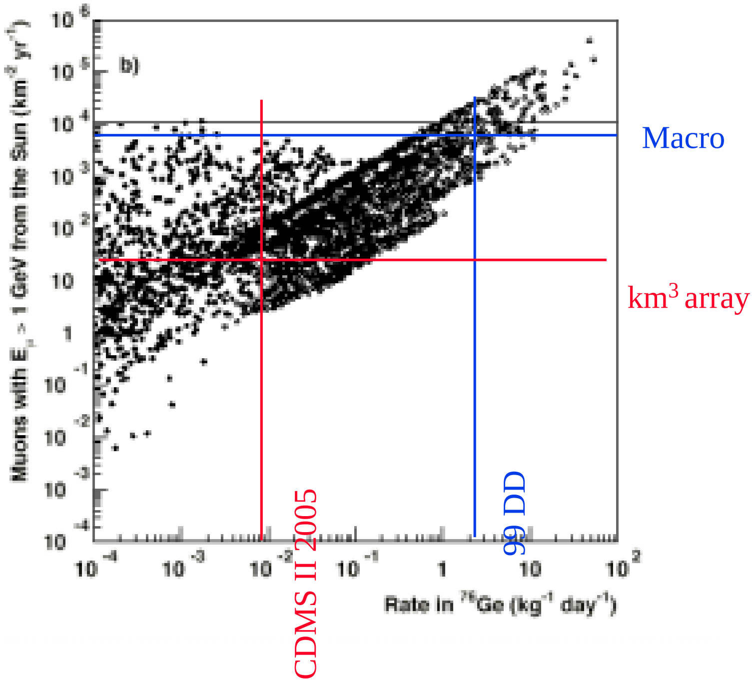
2nd generation of dark matter detector should do better

With future neutrino observatory of 1km^3 and higher threshold (smaller cone), improvement of indirect detection by factor 10-100 at large mass => complementary search ! Bergström et al. , PR D 55(1997) 1765, Astro-ph/9806293

Earth



Sun



Conclusions

Dark Matter=a fundamental question: Baryonic vs non baryonic

Need for a systematic mapping of possibilities

Two priorities • Understand nature of MACHOs

• Vigorous searches for non baryonic dark matter

The searches for the three main non baryonic candidates begin to reach cosmological sensitivities

Axion at KSFZ in lowest mass range

Neutrinos at least the density of stars

WIMPs: even if DAMA claim is premature, we enter supersymmetric territory

Clearly complementary to searches at accelerators

Axions and supersymmetry

Particle astrophysics as a tool of the field

Need for vigorous R&D : best sensitivity, best background

Examples of the cryogenic detectors, liquid Xe and low pressure TPC

Is it the whole story?

Fundamental question raised by current astrophysics: why Ω_{ν}¡ Ω_{b}¡ Ω_{DM}¡ Ω_{Λ}

Do we really understand gravity?