# Physics at Underground Labs: Dark Matter and $\beta\beta$ searches

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Summary:

- The challenge of Rare Events
- Underground Labs
- Dark Matter
- Double Beta Decay
- Latest experimental status
- Future prospects

# The challenge of Rare Events

- Need for **large target masses**
- Need for **very low background** → extreme radiopurity, shielding, event discrimination.
- Need for **very good stability** of operation (very large exposures)
- **Simplicity in** operation and construction is a bonus.
- **Low threshold** (for WIMPs)
- **Good energy resolution** (for DB)

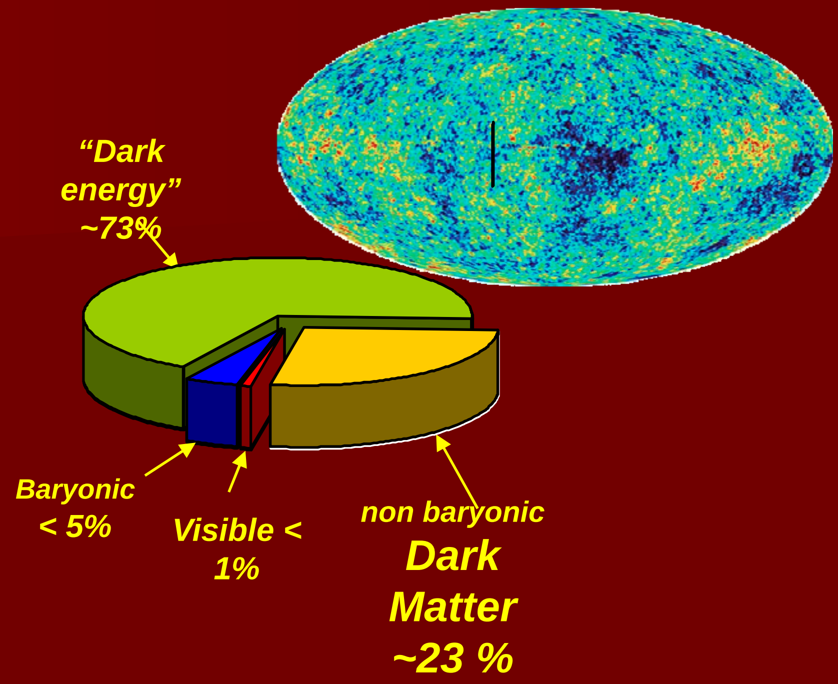
All these requirements add up to a formidable challenge

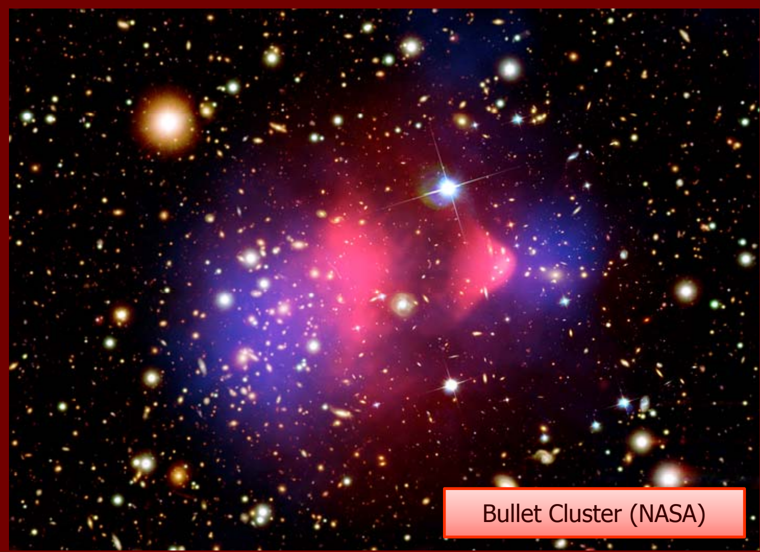
+
Construction & Operation underground

# Deep Underground Labs

# Dark Matter

- Cosmological evidences:
  - Multiple CMB observations. Last WMAP precision data adds evidence for $\Lambda$CDM cosmological model.
  - Distant Supernova Ia measurements (universe is accelerating its expansion → Dark energy).
  - Large Scale Structure (cold dark matter).
  - Nucleosynthesis, Lyman $\alpha$ forest, …
- Galactic evidences:
  - Galactic rotation curves
  - Gravitational mass of galaxy clusters (oldest evidence; 1933 Zwicky)
  - …





Bullet Cluster (NASA)

# What can Dark Matter be?

- Baryonic matter? **NO**
  - Dust, gas, planets, brown stars,… MACHOS (non visible conventional matter)
  - Ruled out by primordial Nucleo-synthesis, and the rest of cosmological observations.
  - Gravitational lensing of MACHOS → not enough
- Non baryonic, but standard, matter? **NO**
  - Neutrinos would be the only candidate in the SM. Ruled out by cosmological observations (they would constitute Hot Dark Matter)
- Non baryonic, beyond standard? most probable

# Candidates to Dark Matter

- Two main candidates attract most of the present activity in the field:

**WIMPS**

Neutral
Heavy
Fermion

- Like the LSP of supersymmetric theories (usually the neutralino).
- WIMP stands for Weakly Interacting Massive Particle (generic name).

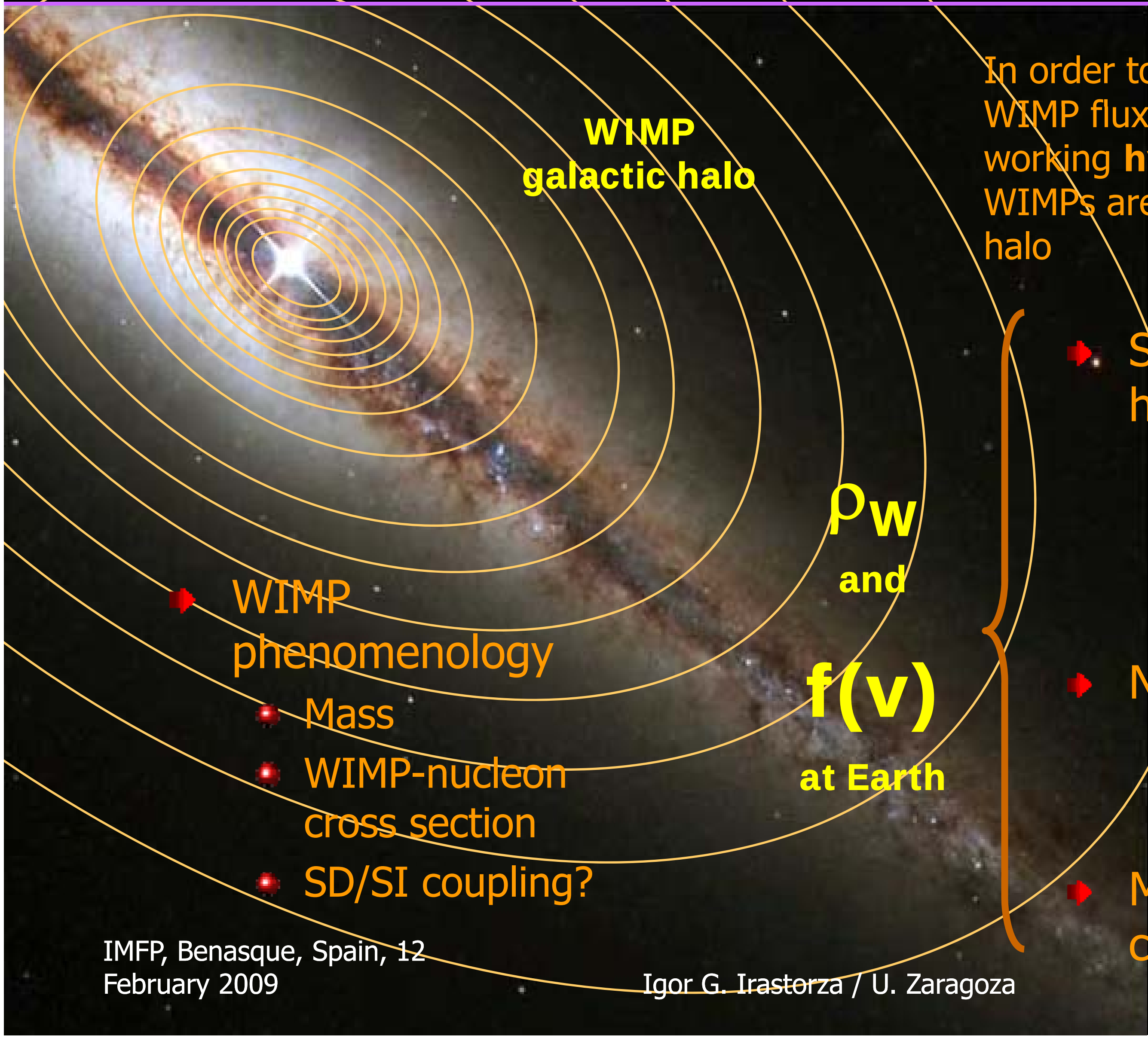
**AXIONS**

Neutral
Very light

(pseudo)scalar

- Axions appear as Nambu-Goldstone bosons in the PQ spontaneous symmetry breaking.
- More generically, we speak about **axion-like** particles, to refer to fundamental (pseudo)scalars of similar properties without referring to a specific theory model.

# Dark Matter WIMPs detection

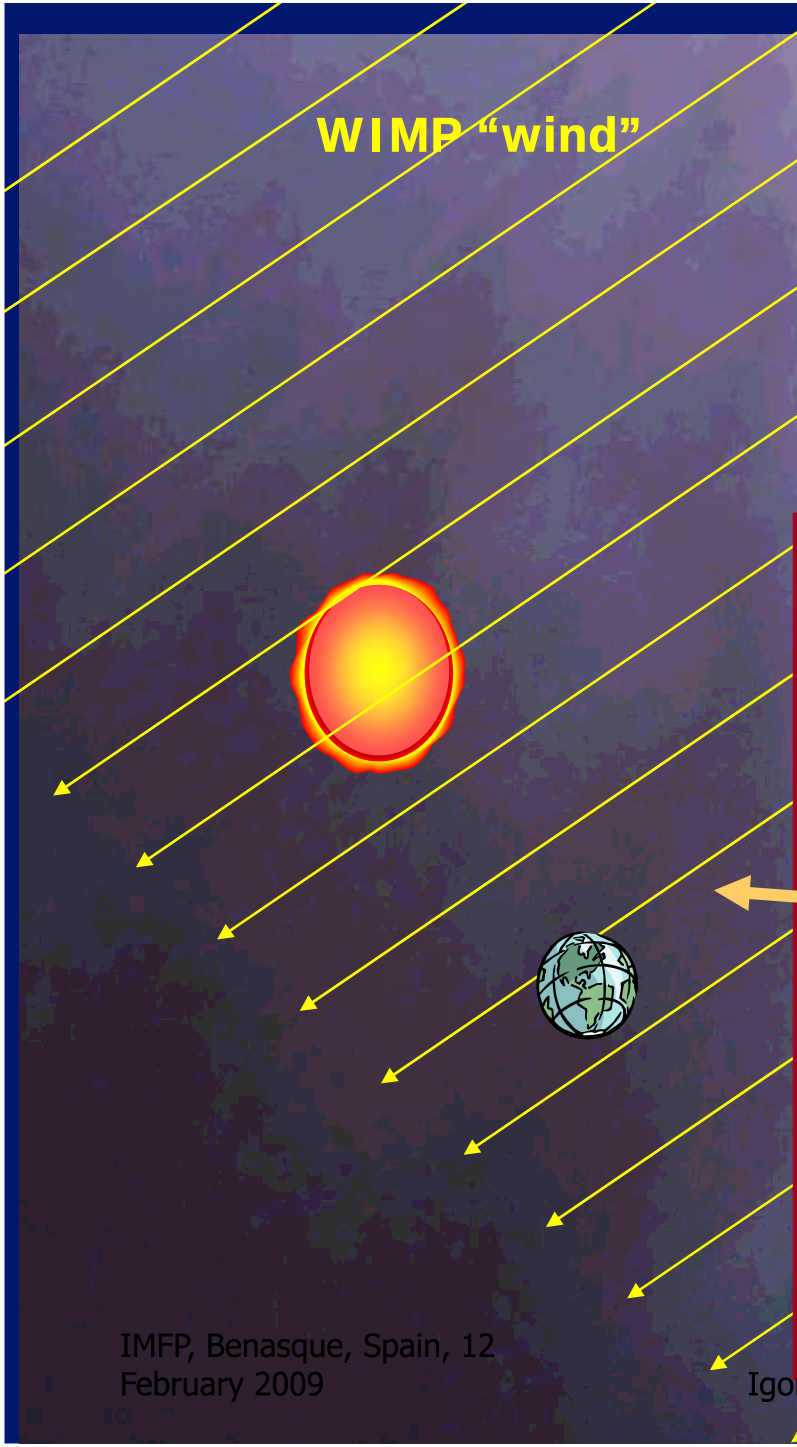



In order to do predictions of expected WIMP fluxes/signals one has to make working **hypothesis** about how WIMPs are clustered in the galactic halo

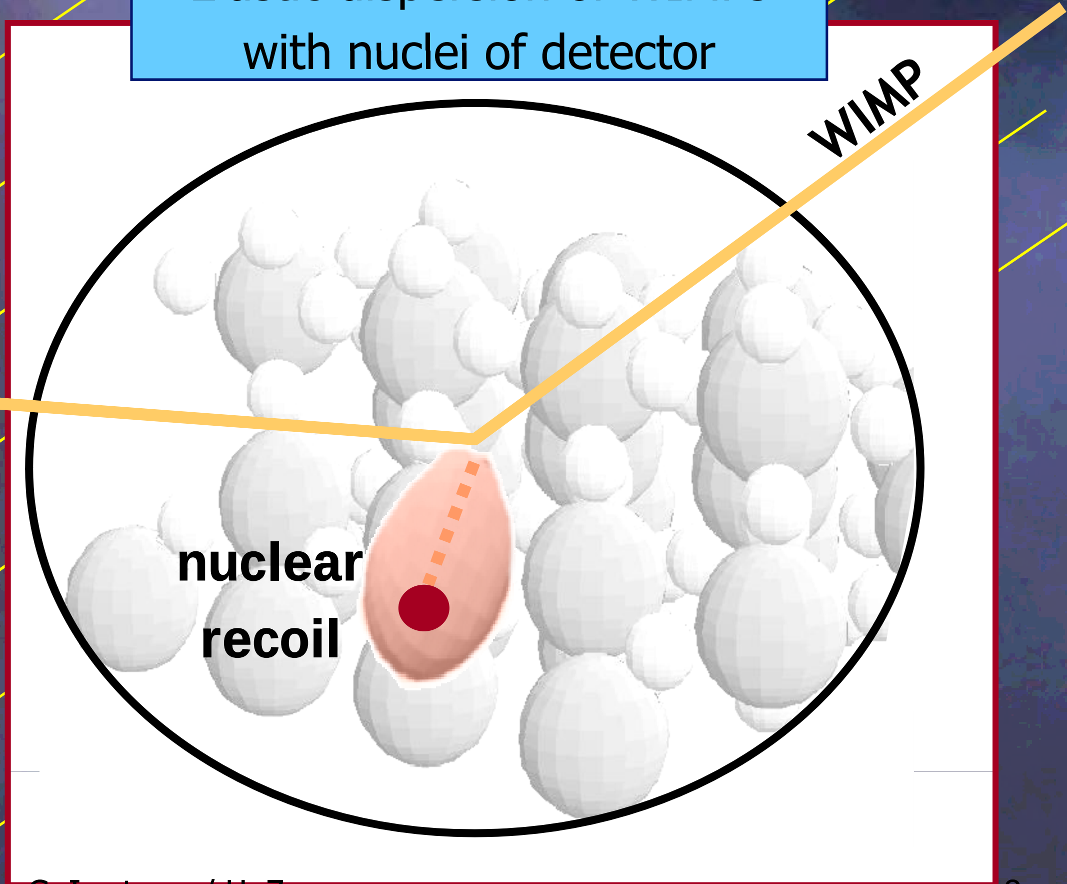
- Standard (=simpler) halo model
  - **Sphericity**
  - **Isotropy**
  - **Non-rotation**
  - **Thermalization**
- Non-Standard
  - Relaxing one or more of the above assumptions to some degree
- Must explain rotation curve of Milky Way

- WIMP phenomenology
  - Mass
  - WIMP-nucleon cross section
  - SD/SI coupling?

# WIMP detection



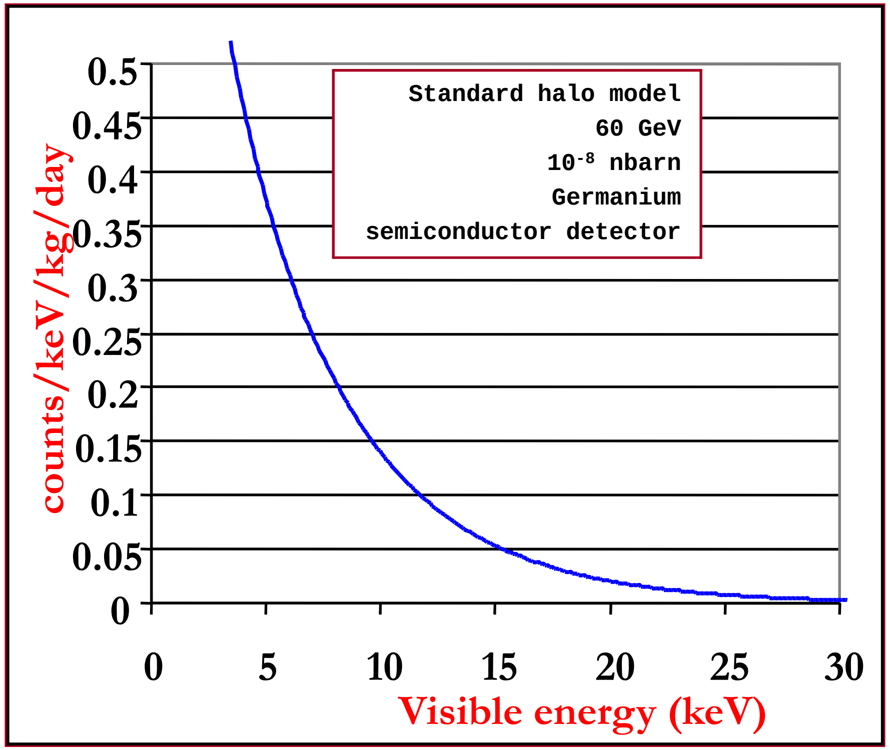

Effect looked for at laboratory:
Elastic dispersion of WIMPs
with nuclei of detector

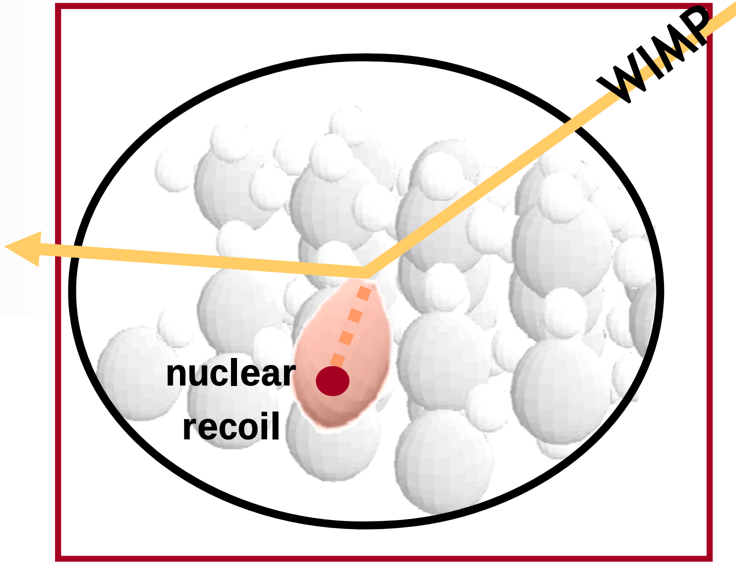


# WIMP detection

- Expected signal:

**rare low energy event**




**Specific challenges:**

✓Low threshold (~keV)

✓Reasonable resolution

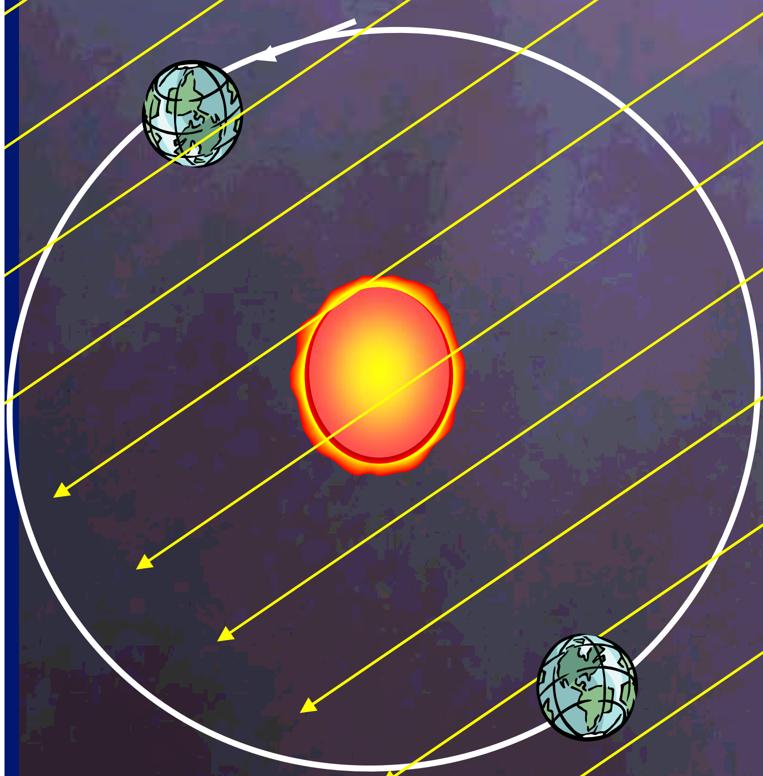
✓Very low background at keV scale:

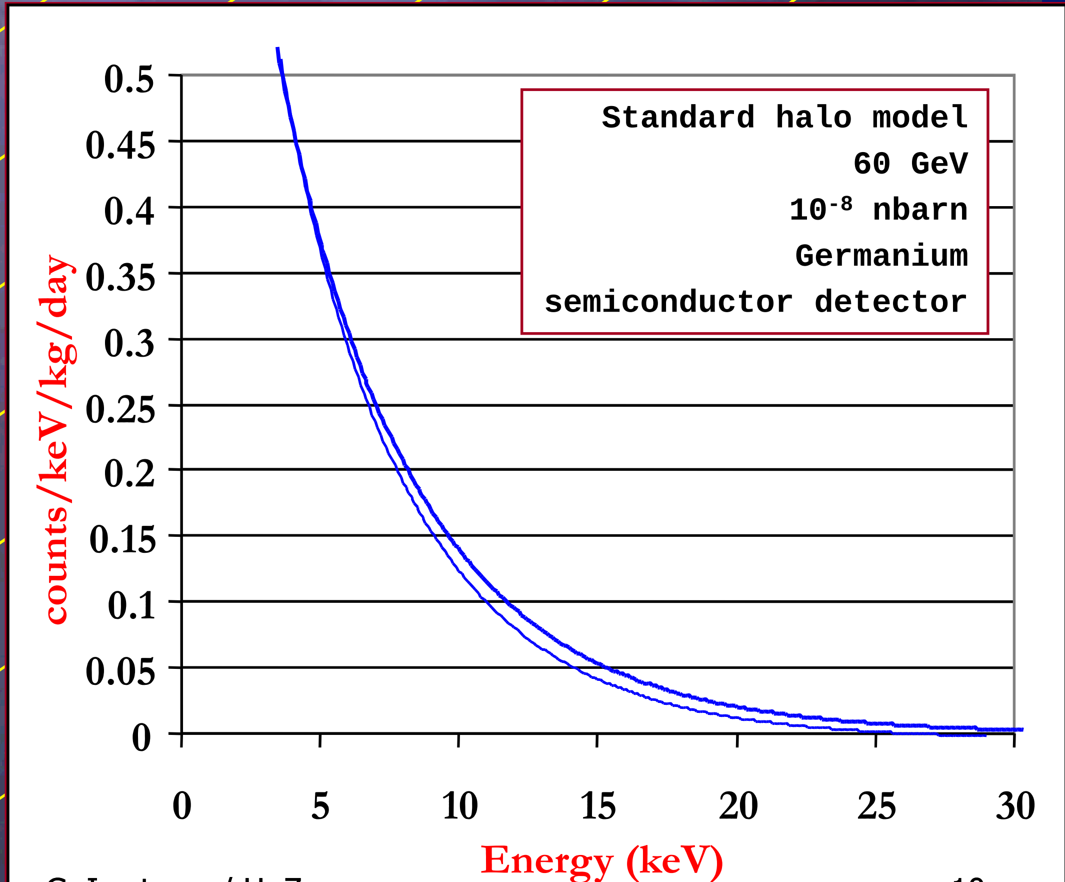
  ✓Radiopurity & rejection techniques

✓Aim for large detector masses

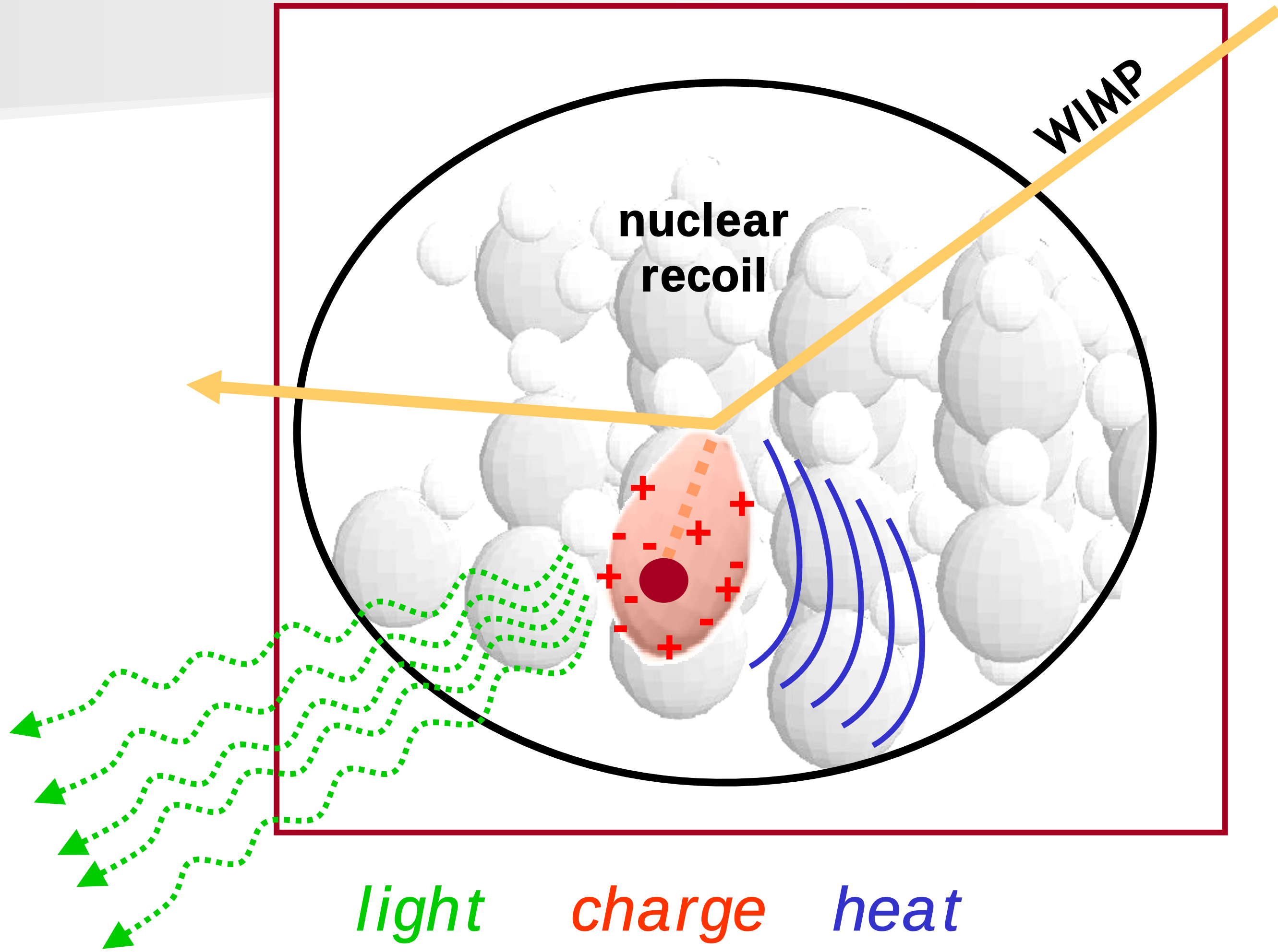
✓Great stability over time.

# Annual modulation signal





# WIMP detection mechanism



Ability to scale-up

Ability of signal identification
(amount of information per event)

Scintillators
(only energy, statistical nuclear/electron discrimination)

DAMA, LIBRA,
ANAIS, KIMS…

Noble Liquids
(nuclear/electron discrimination)

ZEPLIN+, **XENON**,
WARP, ArDM,…

Hybrid bolometers
(nuclear/electron discrimination)
**CDMS**, EDELWEISS,
CRESST, ROSEBUD,

→ EURECA

Gas TPCs
(Recoil direction)
DRIFT, DMTPC, MIMAC…

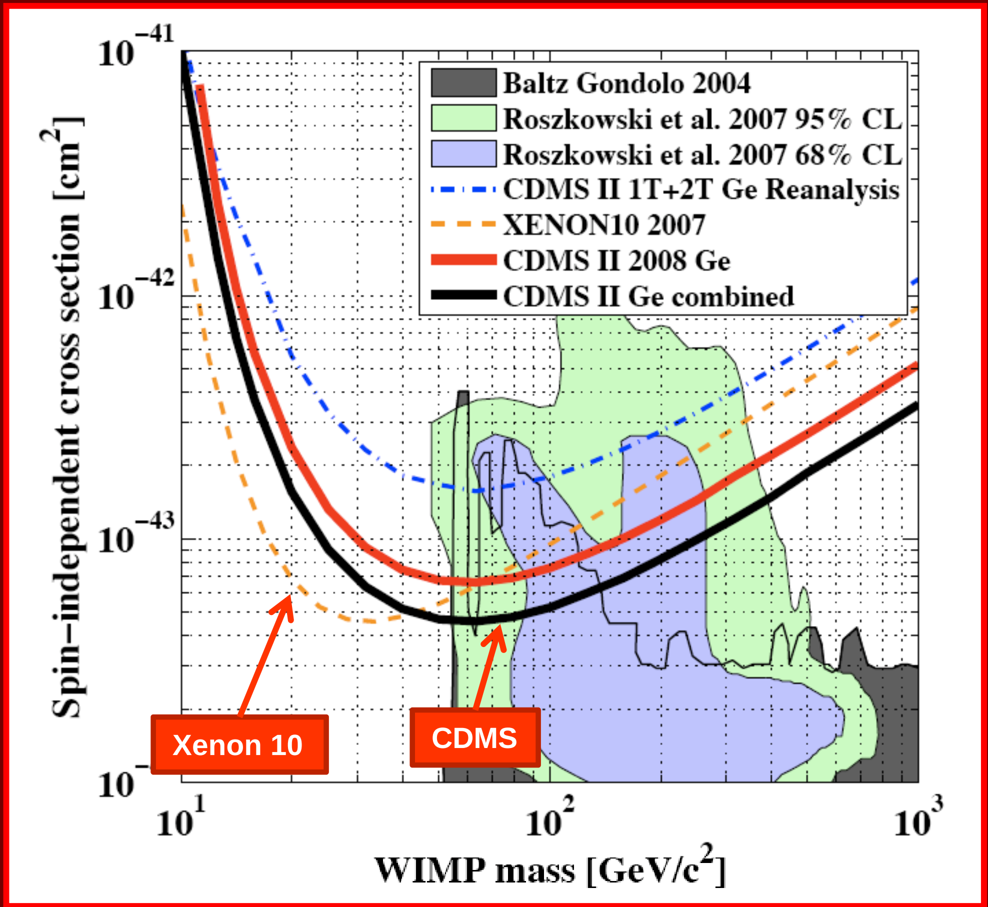
→ CYGNUS

**Best current limits from XENON and CDMS**

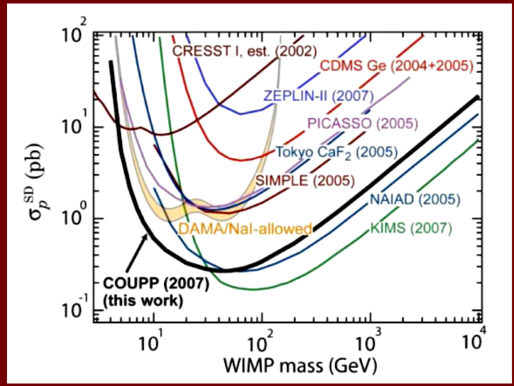
Others: COUPP
best limits for SDp

# Best current limits

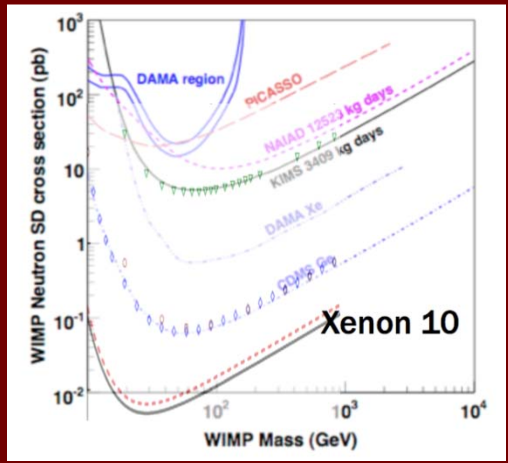
- SI coupling




- SD coupling proton

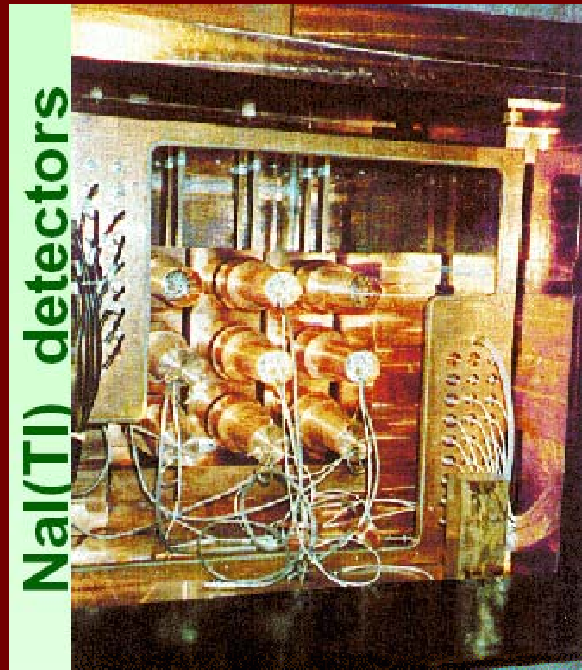



- SD coupling neutron



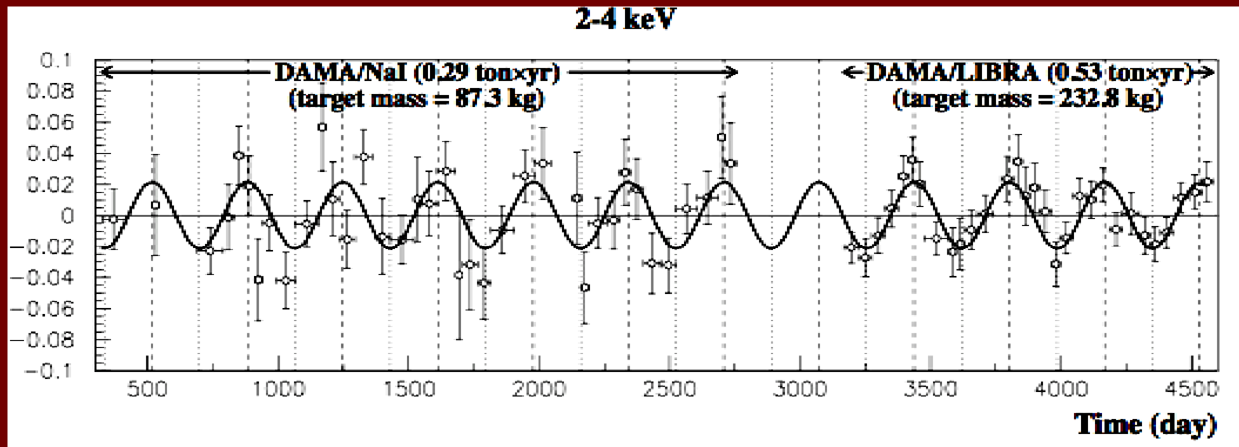
# DAMA-LIBRA

- DAMA: 100 kg of ultrapure NaI(Tl) operating for about 7 years at Gran Sasso
- Looking for annual modulation of the data
- LIBRA: 250 kg. Operated for 4 years (09/03 to 07/07), twice the exposure fo DAMA



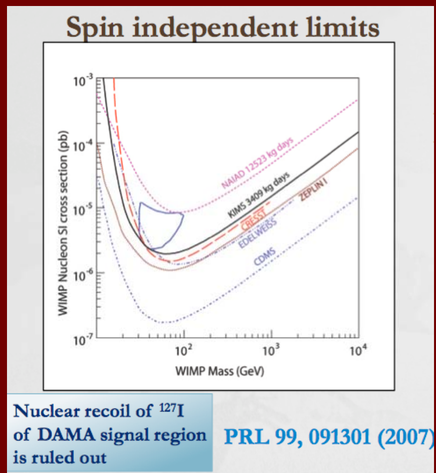

**POSITIVE CLAIM**

- 6.3$\sigma$ statistical significance went up to 8.2$\sigma$ after LIBRA.
- No systematic effect found that can mimic that signal
- Modulation absent above 6 keV



# DAMA Positive result: WIMP interpretation

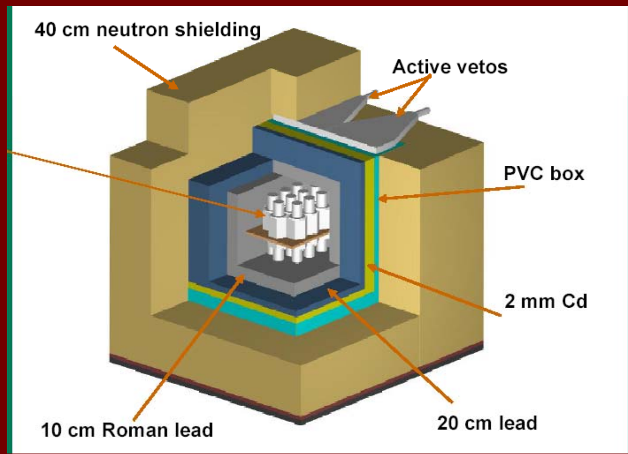
- No systematic effect can explain it satisfactorily (neutrons, temperature,…)
- Classical WIMP excluded by other experiments, but some marginal options (non-standard set of assumptions) at low mass…




- KIMS in Korea:
  - CsI crystals

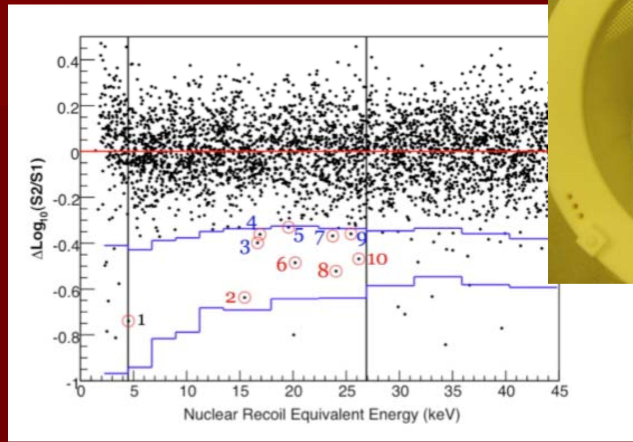
- Alternative solutions.

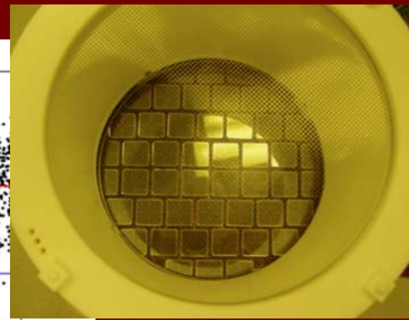
- Other NaI experiments that could refute/corroborate DAMA result
- ANAIS in Canfranc:
  - Prototyping phase finished.
  - 100 kg available, being instrumented.




# Noble Liquid detectors: XENON

- XENON10 at Gran Sasso: one of best exclusions up-to-date
- 4.5 kg fiducial mass, data 58.6 days, 10 events in NR zone
- Now moving to XENON100 (commissioning)



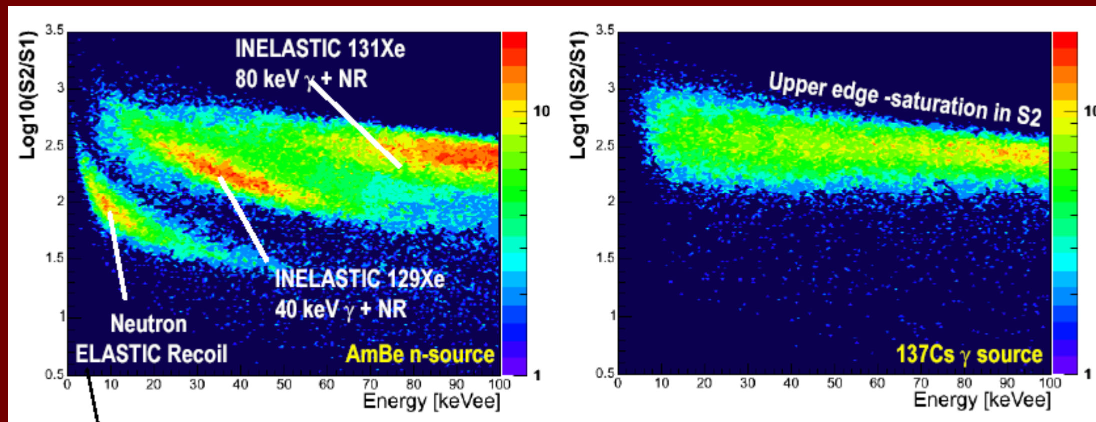



Nuclear/recoil discrimination event by event

Good prospects for scaling-up

Threshold? (rejection power at low energies?)

Self-shielding




Also… ArDM, WARP, XMASS, ZEPLIN,…

# Hybrid bolometers: CDMS

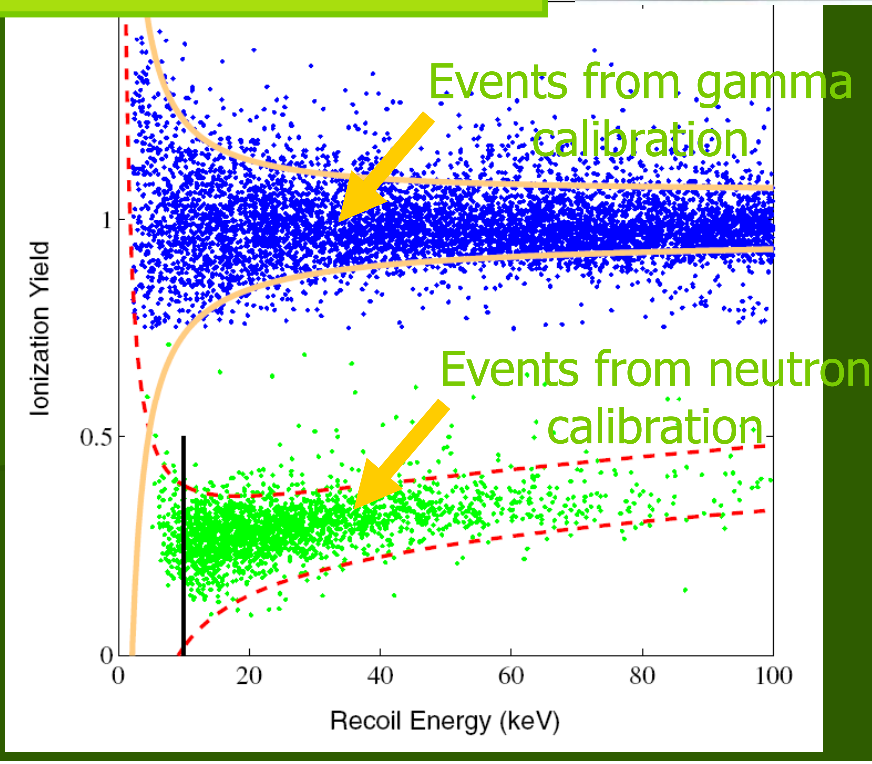
CDMS at Soudan

- 5 tower prototype (5 kgs of Ge) operating underground (+ several Si detectors). But only 1/3 of crystals in good shape.
- 125 kg d of exposure analysed and released in 2008
- 0 observed counts in NR band.

Nuclear/recoil discrimination demonstrated down to 10-15 keVr

Last exclusion plot (2008) competes with that of XENON

- Also EDELWEISS at Modane
- 12 * 400 g detectors installed in EDWII now



# Hybrid bolometers: Heat+light

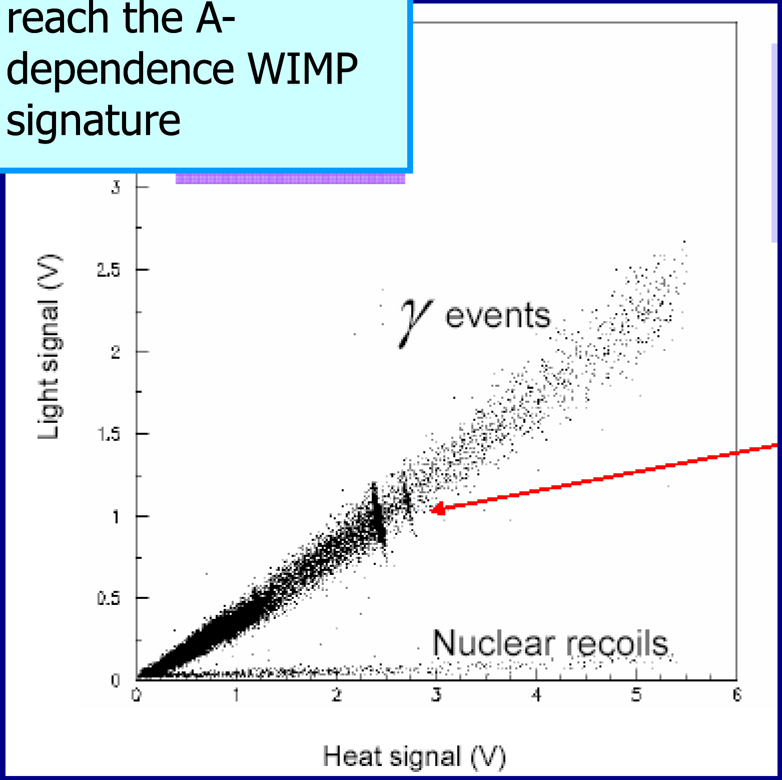
## ROSEBUD-II at Canfranc

- Concept first applied underground.
- Discrimination down to 8-12 keVr demonstrated.
- Only low mass prototypes tested.
- Work towards multitarget setup

- Nuclear/recoil discrimination
- Only technique with good prospects to reach the A-dependence WIMP signature

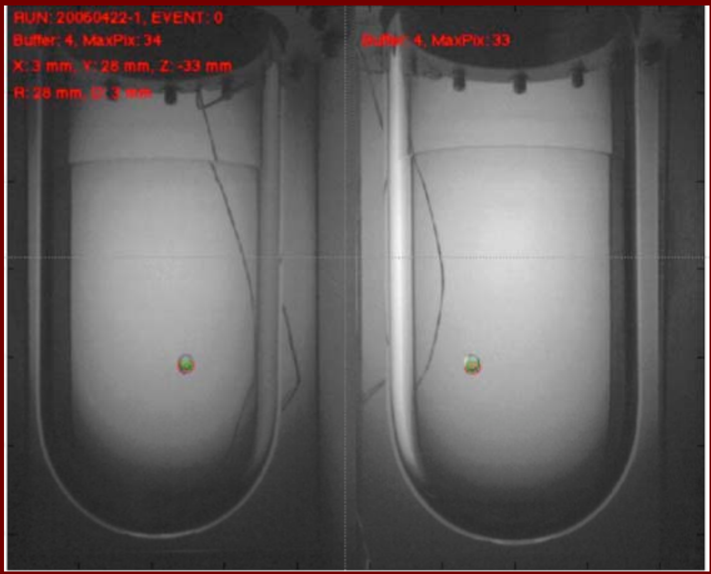
## CRESST-II at Gran Sasso

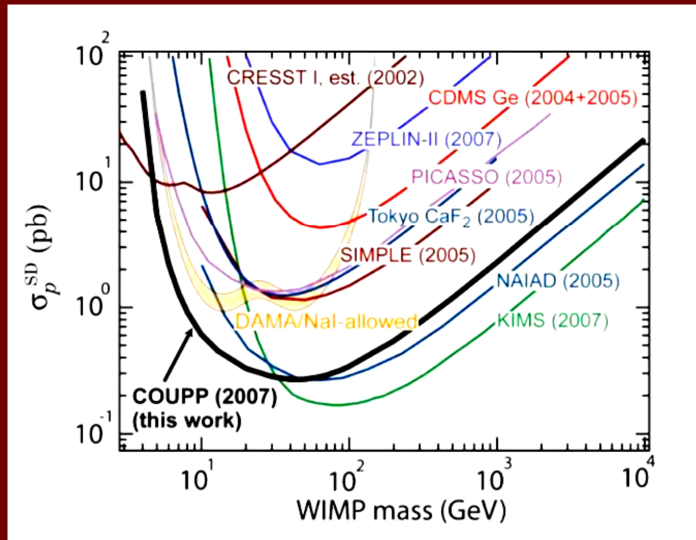
- Discrimination between different nuclei recoils (W and O) in same crystal.
- 20 kg d of $CaWO_2$ reported. Competitive exclusion produced.
- Work ongoing towards 10kg prototype.



# COUPP at Chicago

- The old bubble chamber concept.
- Insensitive to gamma backgrounds
- No energy info (digital response). But tuning of threshold allows energy scan
- Good sensitivity with 19F nucleus to SD pure p couplings (even in presence of high radon background)
- Good scaling-up prospects





# Low WIMP mass limits

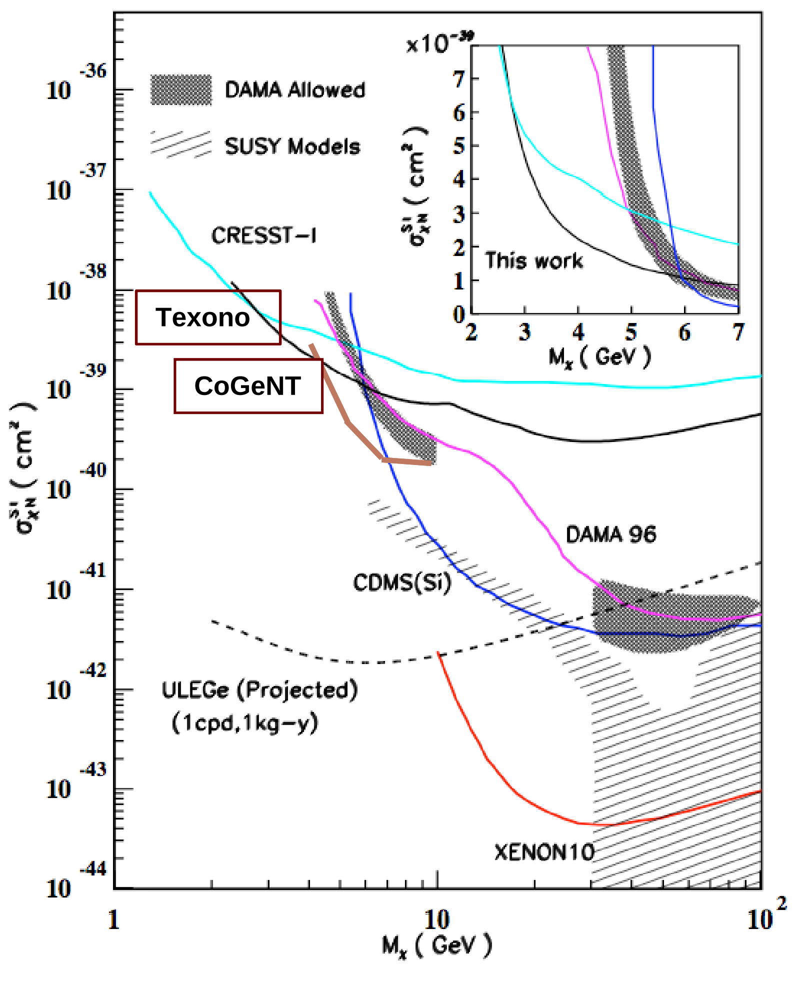
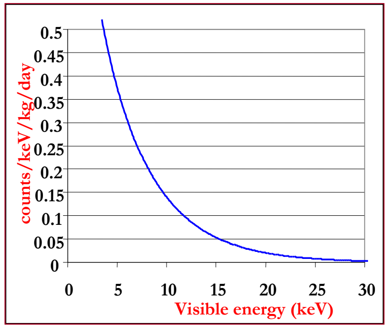
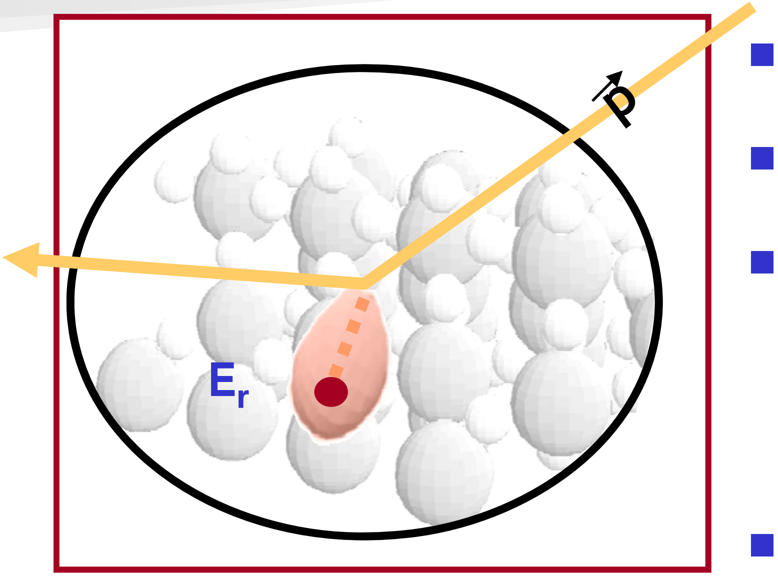


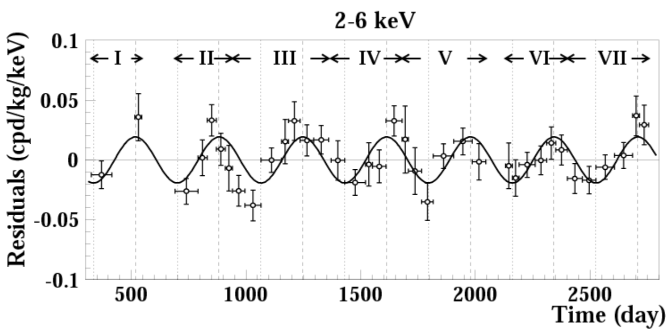

FIG. 5: Exclusion plots of spin-independent $\chi$N cross-section

- To access low mass region (< 10 GeV) → thresholds below 1 keV
- Non discriminating techniques (CRESST, Texono, CoGeNT)
- Interest → models making DAMA compatible with others (now covered by CoGeNt)
- Still limits are 3.5 orders of mag higher @ 6 GeV than @ 60 GeV

# WIMP signatures/features

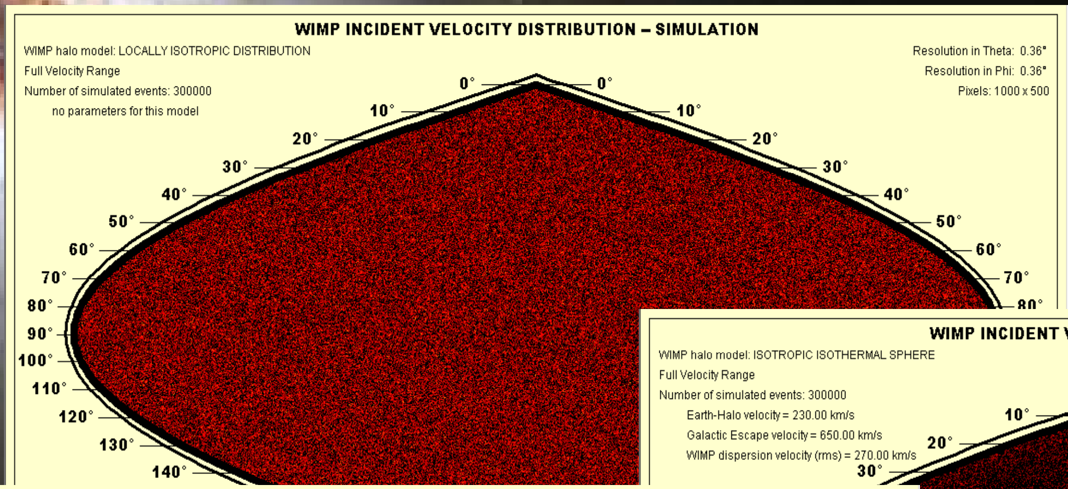


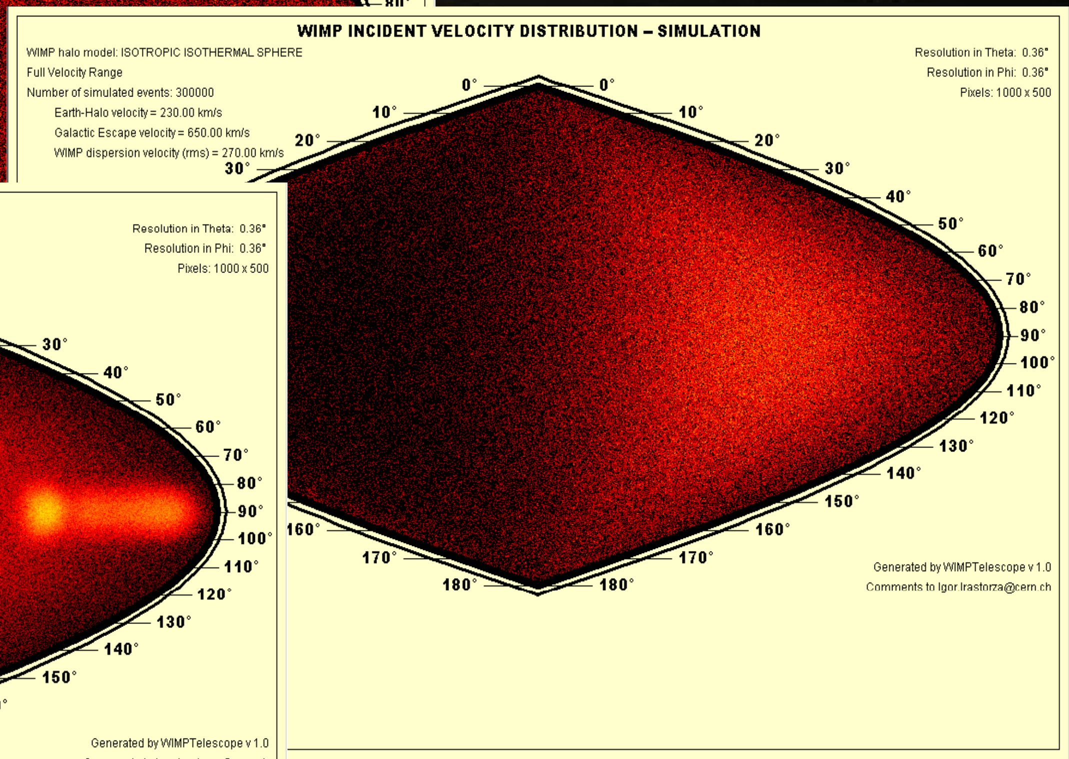



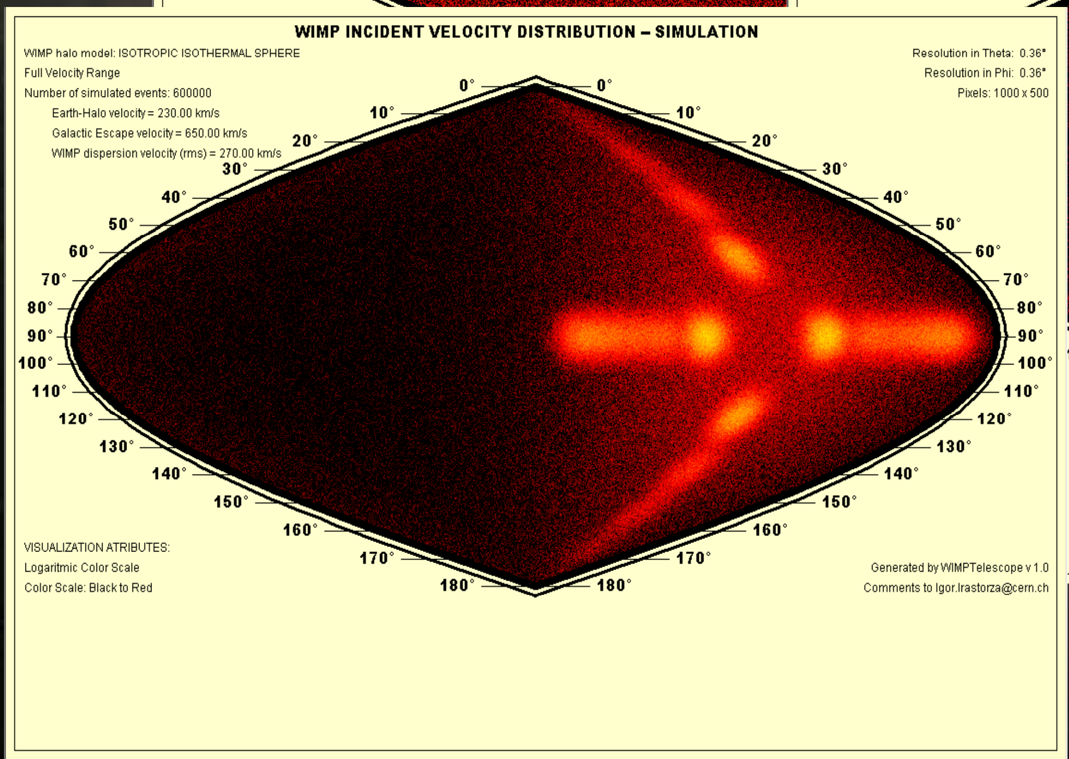

- $E_r$ spectrum: very poorly identificative
- Nuclear/electron discrimination (leading present techniques)
- Independence of position (important for future larger detectors)
- **Rate changes**:
  - **Annual modulation**: at reach if large target mass (DAMA,…)
  - Diurnal variation. Some attempts in the past (COSME, SIERRA GRANDE). Very large statistics needed.
- **Target material dependence**:
  - Challenging, but good progress (ROSEBUD-II, CRESST-II). Maybe at reach soon.
- **Directionality**:
  - Challenging. Good progress (DRIFT, NEWAGE,…). Maybe at reach soon.

# Directional signal




**Background is isotropic**




**While the signal is not**

# Directional detectors R&D

## DRIFT

- Negative Ion TPC concept proved by DRIFT-I.
- DRIFT-II: 2nd 1m3 TPC installed underground and taking data.
- Work towards increasing volume instrumented.

DRIFT-I

DRIFT-I @ Boulby

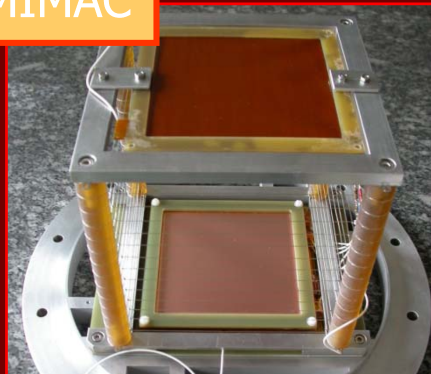
- Potentially the best WIMP signature
- Still clear demonstration of directionality threshold and resolution missing.
- scaling-up?
- Use of new technologies in TPCs?

NEWAGE

microdots

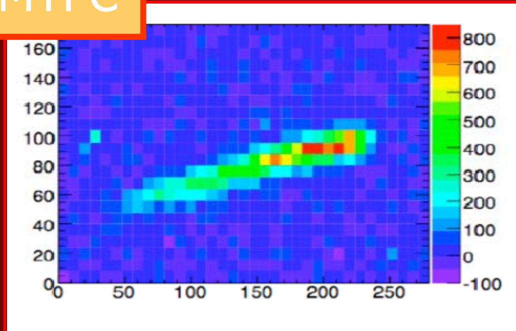
MIMAC

GEM/MMs



DMTPC

Optical readout




The future... CYGNUS ?

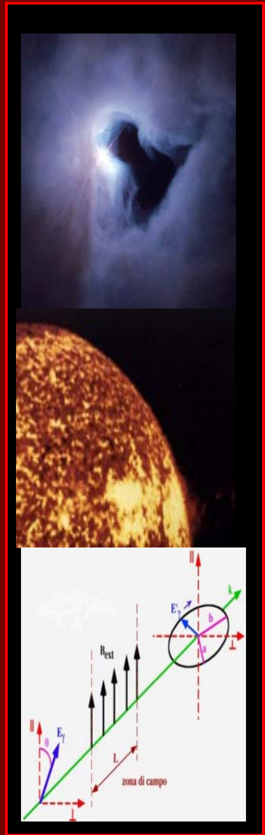
# Future of WIMP detection

- Presently (too?) many different techniques being explored. (→positive side). Time to concentrate efforts?
- What is the most promising technique (or techniques) ?
- Not a clear answer yet. But maybe is time to start evaluating and forming bigger collaborations and experiments (it is indeed being done → ILIAS)
- Protocollaborations for bigger experiments gathering all groups following a given technique? (EURECA for bolometers, ELIXIR for noble liquids, CYGNUS for direccionality… ??? )
- In any case, very exciting moment for WIMP searches

# But what if there are no WIMPs… but AXIONs?

- Axions are searched in 3 different contexts (different sources of axions):
  - Dark matter axions (as relics of Big Bang):
    - Axion Haloscopes (**ADMX**, CARRACK)
  - Axions produced in the Sun:
    - Axion Helioscopes (Kyoto, **CAST**)
    - Crystal detectors (SOLAX, COSME, DAMA)
  - Axions produced in the laboratory
    - "Light shinning through wall" experiments
    - Vacuum birrefringence experiments

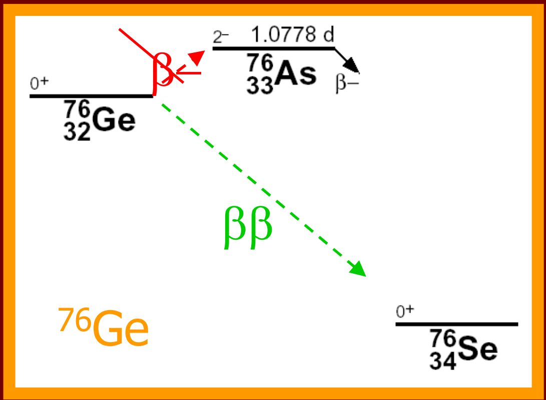
    PVLAS, ALPS, OSQAR, BMV, …

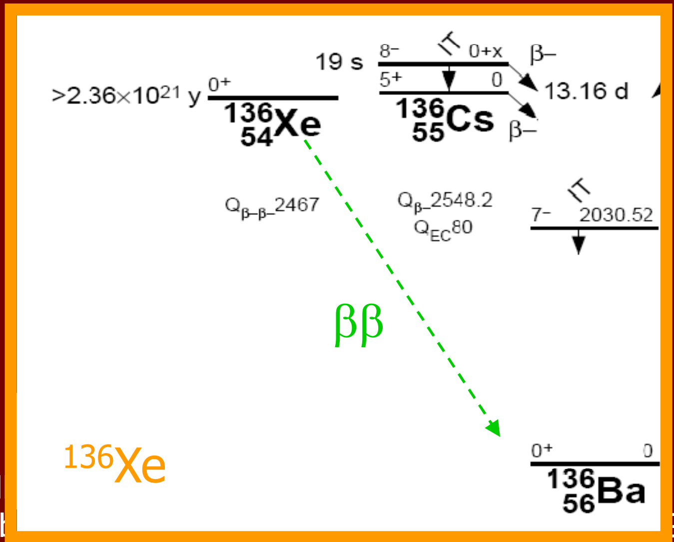


In general not in Underground Labs

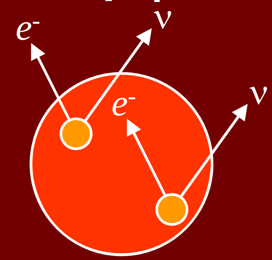
# Neutrinoless Double Beta ($0\nu\beta\beta$)

- $\beta\beta$ decay is relevant when the nucleus cannot decay $\beta$.

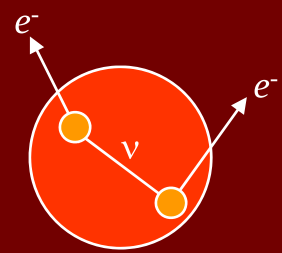



- ✓ With emission of 2 $\nu$ ($2\nu\beta\beta$). Standard process, observed in a number of isotopes.



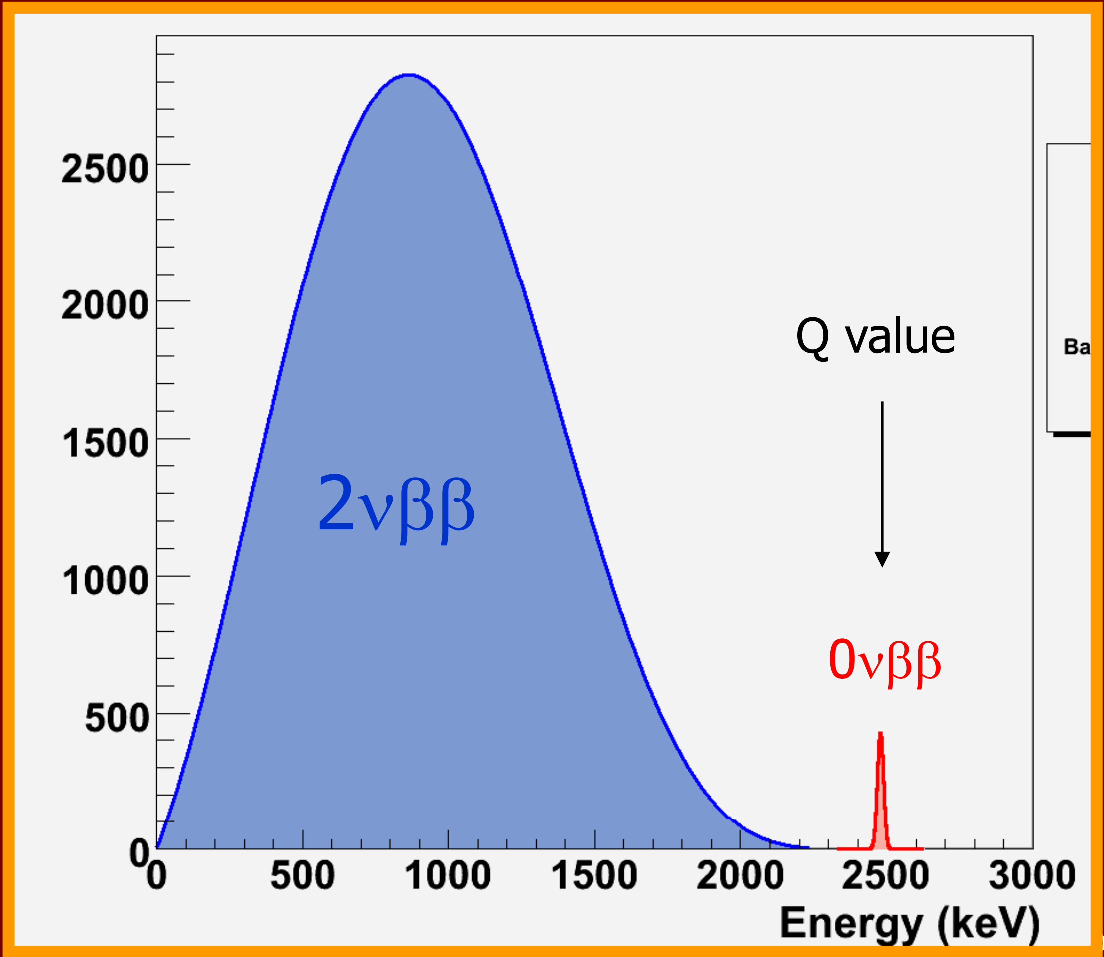

- ✓ With no neutrino ($0\nu\beta\beta$). Only possible if neutrino is massive and Majorana. Not yet seen(*).

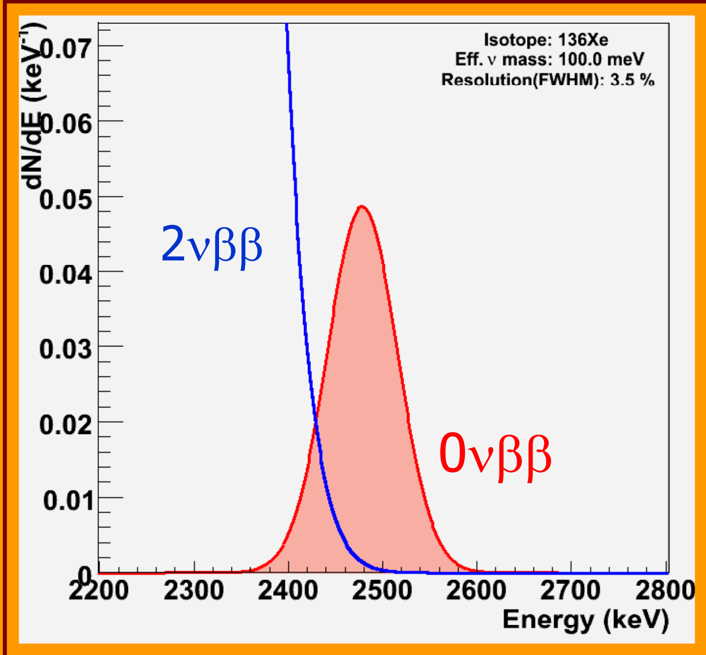



- Precious information on neutrino properties (mass scale, Majorana/Dirac nature,…)

# Neutrinoless Double Beta ($0\nu\beta\beta$)

- "Visible" energy (i.e. the 2 $e^-$) spectrum:



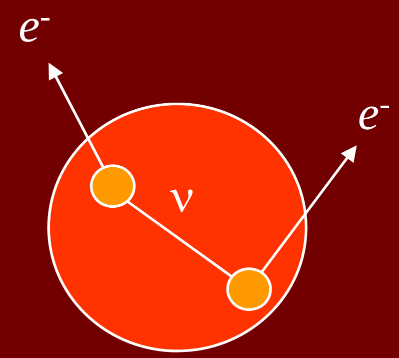




- Energy resolution very important.

**Only way to distinguish between both processes**

# Neutrinoless Double Beta (0νββ)

- (A,Z) → (A,Z+2) + 2 e⁻
- Lepton number violation (ΔL =2)
- Neutrino must be Majorana (equal to its antiparticle)
- Decay rate:




Phase space factor

Nuclear Matrix Element

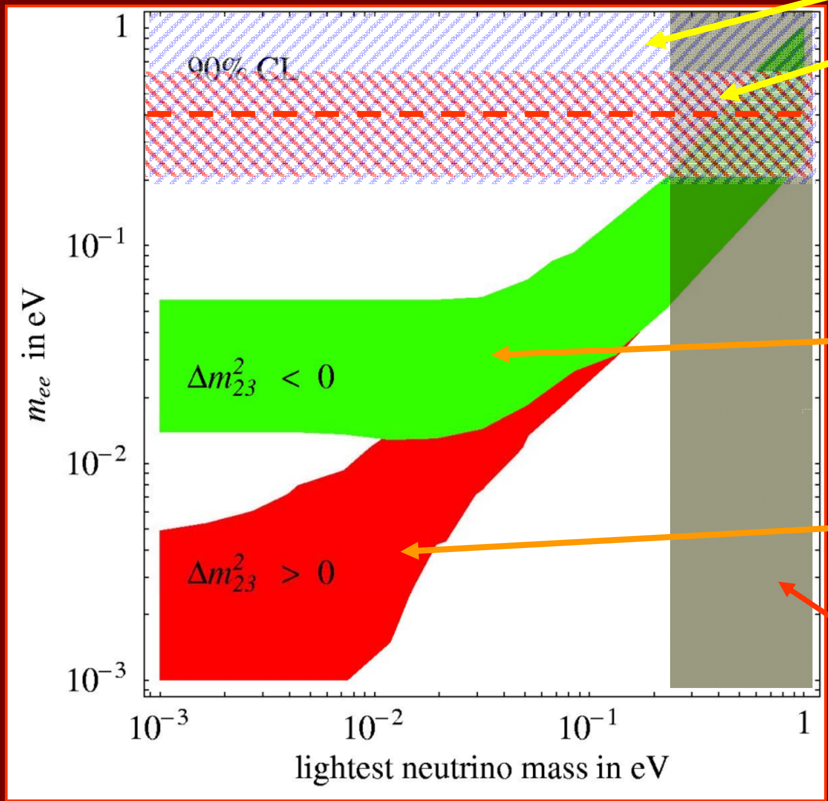
$$\Gamma = G|M|^2|m_{\beta\beta}|^2,$$

- Effective neutrino mass is the underlying quantity (assuming light neutrino exchange as fundamental process, others possible)

$$m_{\beta\beta} = \sum_{i=1}^{3} m_i U_{ei}^2.$$

# Neutrino mass scale and 0νββ

- IGEX ($^{76}Ge$) $<m_\nu> < 0.33 - 1.35$ eV PRD65(02)092007
- NEMO-3 ($^{100}Mo$) $<m_\nu> < 0.6 - 1.3$ eV PRL95(05)182302 & talk @ TAUP07
  expected soon $< 0.3 - 0.7$ eV
- CUORICINO ($^{130}Te$) $<m_\nu> < 0.2 - 1.1$ eV PRL95(05)142501




Region being explored by present experiments

Claimed evidence (0.2-0.6 eV)
PLB586(04)092007

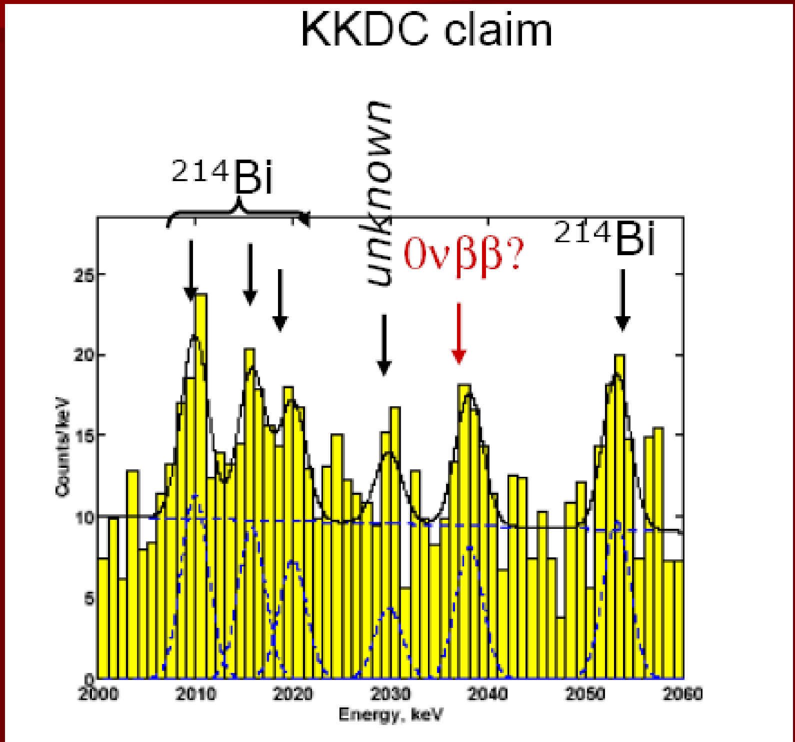
"quasi" degeneracy
$m_1 \approx m_2 \approx m_3$

Inverse hierarchy
$\Delta m^2_{12} = \Delta m^2_{atm}$

Direct hierarchy
$\Delta m^2_{12} = \Delta m^2_{sol}$

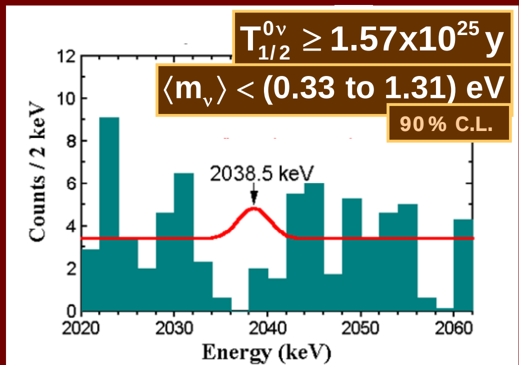
Cosmological disfavoured Region

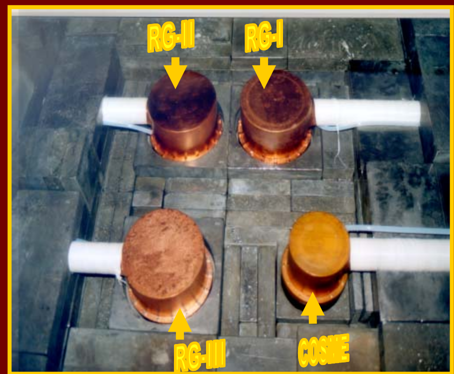
# KKDC Claim



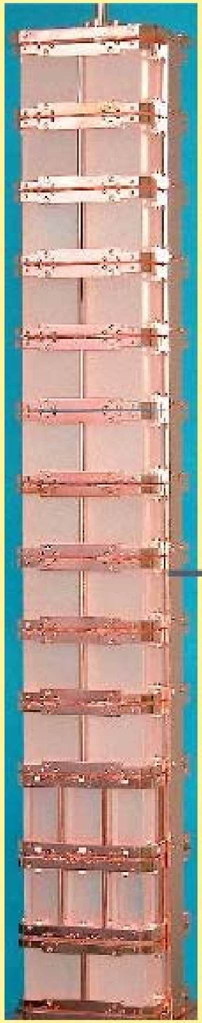

$< m_\nu >= 0.1 - 0.9\,\mathrm{eV}$ (KKDC, 2004)

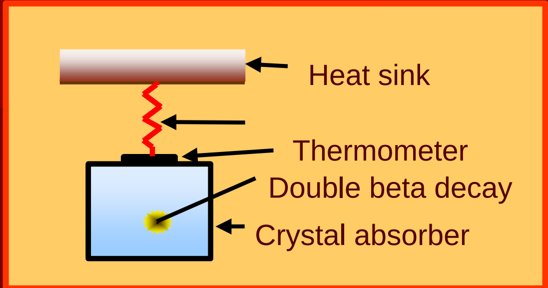
- Heidelberg Moscow experiment data at Gran Sasso.
- >4 $\sigma$ claimed.
- Criticisms:
  - Background not explained
  - Unknown line
  - Only signed by part of the H/M collaboration
  - …
- Similar exp, IGEX @ Canfranc



# Latest limits: CUORICINO

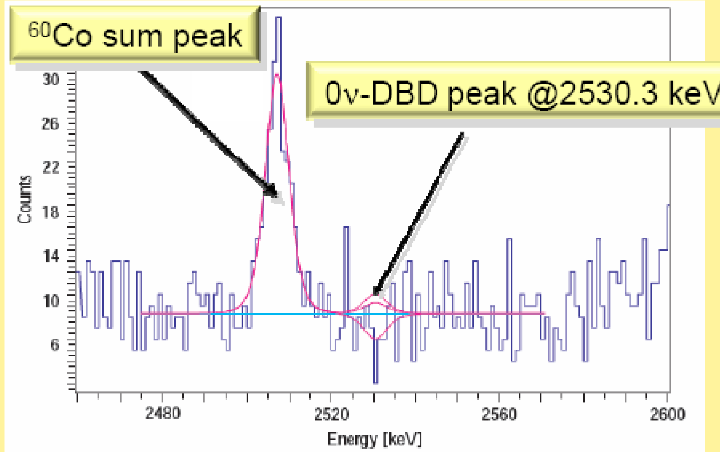





- Source: $^{130}$Te. High natural abundance (33.9%). High Q-value (2530 keV).
- Detectors: bolometers of TeO2.
  - 11 modules of 4 crystals each 5x5x5 cm3. 2 modules for 9+9 3x3x6 cm3 crystals.
- Mass: 40.7 kg TeO2. 11 kg of $^{130}$Te
- Background: 0.18 c/keV/kg/y

Total statistic ~ 15.53 kg ($^{130}$Te) × y
data analyzed up to August 2007

...at Gran Sasso




*Anticoincidence background spectrum: the **bb**-0**n** region*

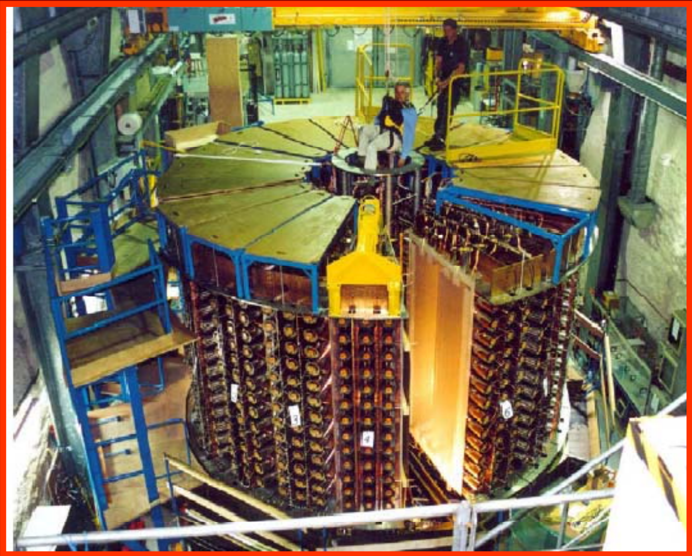
$$\tau_{1/2}^{0\nu} \geq 3.1 \cdot 10^{24}\ y\ (90\%\ CL)$$

$$\Rightarrow \langle m_\nu \rangle \leq 200 - 680\ meV^*$$

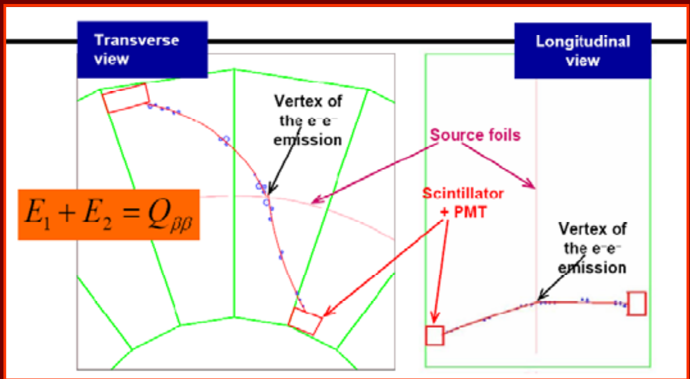
*From C. Brofferio, Neutrino2008

# Latest limits: NEMO3

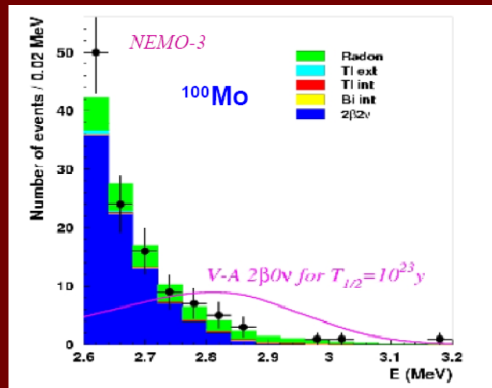
…at Modane (LSM)



- Source: 10 kg of bb isotopes (in foils). Change of isotope possible. $0\nu\beta\beta$ searched in $^{100}$Mo, $^{82}$Se and $2\nu\beta\beta$ in $^{116}$Cd, $^{96}$Zr, $^{150}$Nd, $^{48}$Ca, $^{130}$Te.
- Foils are sandwitched between tracking detectors (Geiger cells) plus calorimeters. B field and shielding.
- Particle ID possible: e-, e+, $\gamma$, $\alpha$.

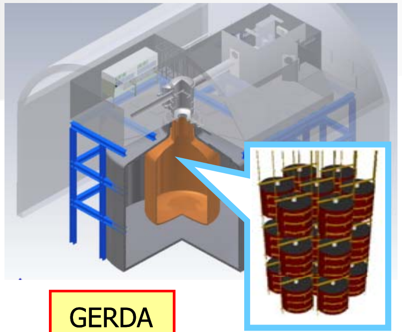



- **$<m_\nu> < 0.8 – 1.3$ eV**
- (from the $^{100}$Mo result).
- Still taking data till 2010.



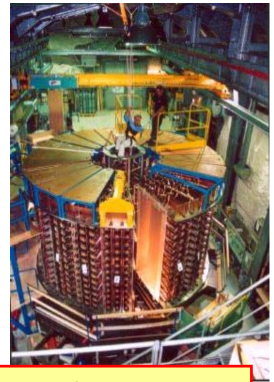
# Current generation $\beta\beta$ experiments

- Source = target
- Good E resolution
- Good scaling-up
- BUT, modest background discri. →strong requirements on radiopurity and shielding



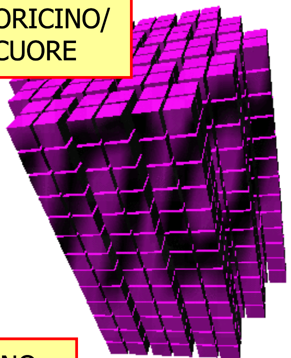
GERDA

- Source ≠ target
- Event topology information
- BUT, moderate energy resolution and difficult scaling up

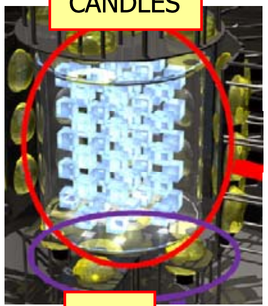


NEMO/SUPERNEMO

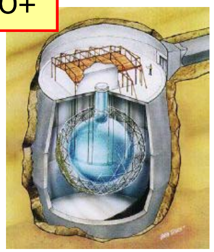
CUORICINO/ CUORE



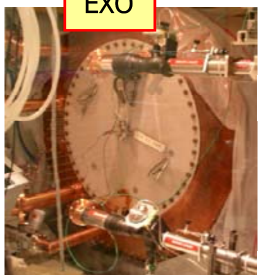
CANDLES



SNO+



EXO

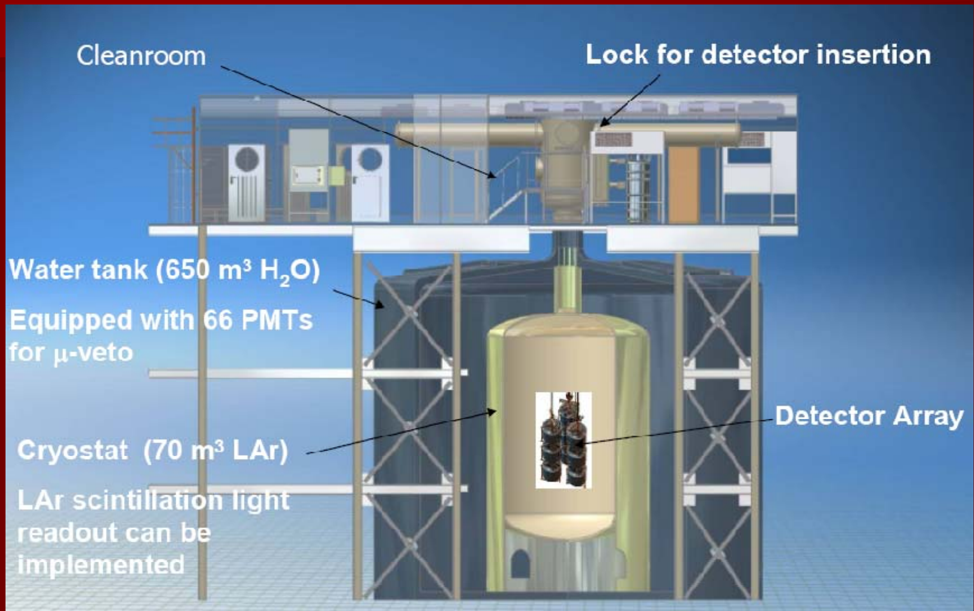


Summary of present situation. Latests experiments & projects

| Isotope | PAST exp's (eV) | Future | Approved scale |
|---|---|---|---|
| $^{76}$Ge | HM, IGEX (0.2 – 0.6) | GERDA, MAJORANA | 40 kg |
| $^{130}$Te | **CUORICINO** (0.2 – 0.6) | CUORE | 200 kg |
| $^{100}$Mo | **NEMO3** (0.8 – 1.3) | MOON II | R&D |
| $^{136}$Xe | Gothard | EXO, NEXT | 200/100 kg |
| $^{116}$Cd | | COBRA | R&D |
| $^{150}$Nd | | SuperNEMO, SNO+ | Design study/R&D |
| $^{82}$Se | NEMO3 | SuperNEMO | Design study |
| $^{48}$Ca | | CANDLES | R&D |

# GERDA: Ge diodes

…at Gran Sasso

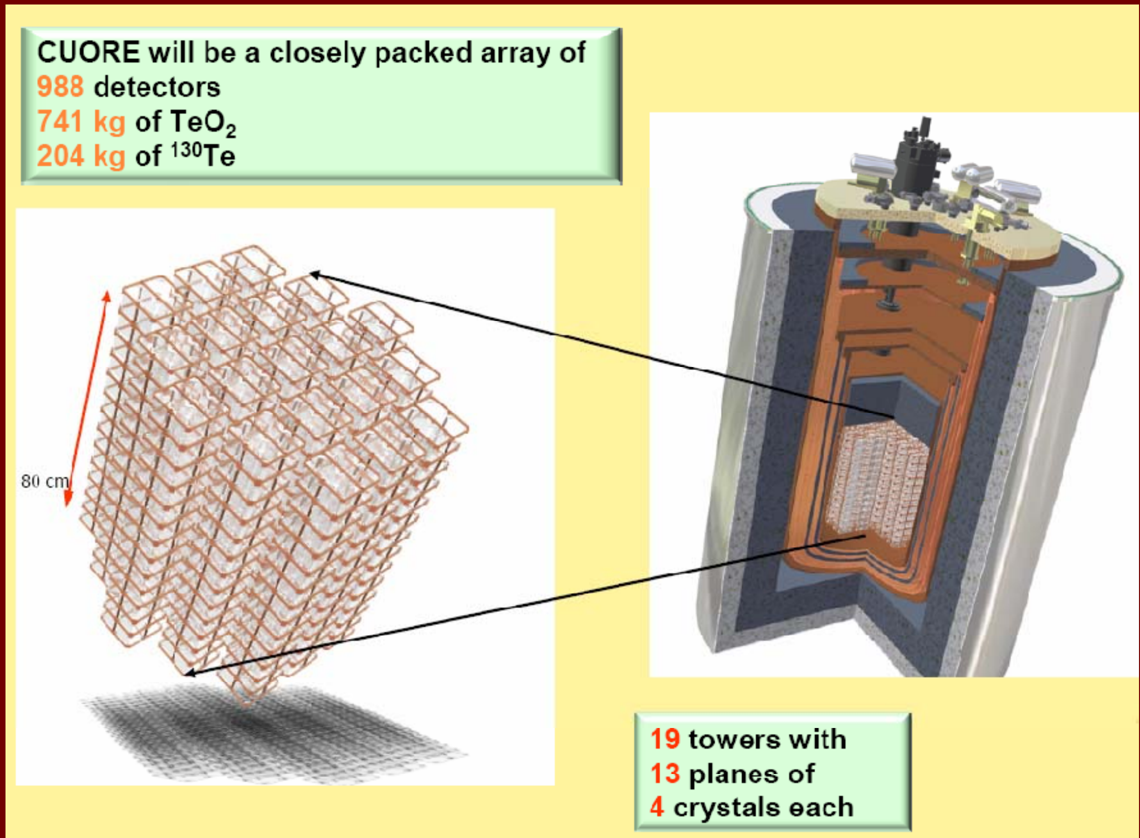



- Phase I:
  - Use of existing $^{76}$Ge-diodes from Heidelberg-Moscow and IGEX-experiments
  - 8 detectors for 17.9 Kg of $^{enr}$Ge
  - Expected Background ~ $10^{-2}$ count/(kg·keV·y) dominated by crystal internal backg. → KKDC evidence verified in an external background-free setup.
- Phase II:
  - Add new diodes (+22 kg, total: ~40 kg $^{enr}$Ge) able to discriminate SSE/MSE.
  - Demonstration of bkg-level <$10^{-3}$ count/(kg·keV·y)
- Eventually Phase III:
  - If background OK
  - If KKDC-evidence not confirmed: $\mathcal{O}$(1 ton) experiment by a worldwide collaboration with Majorana


- Also MAJORANA in the US.
- Possible merging of collaborations in the future (already working together in, i.e. MC sim)

# CUORE: bolometers

- Source: $^{130}$Te. High natural abundance (33.9%). High Q-value (2530 keV).
- Detectors: 988 bolometers (741 kg) of TeO2. (204 kg of $^{130}$Te)



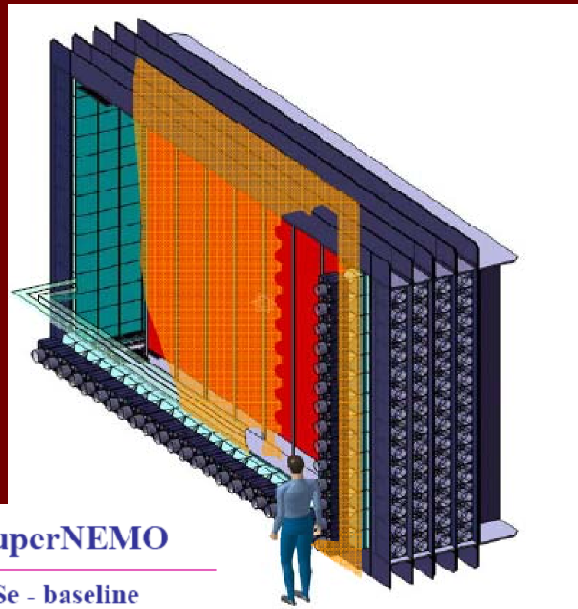

- Expected background:
  $10^{-2} – 10^{-3}$ c/kEV/kg/y
- Expected sensitivity:
  15 – 80 meV (depending on achieved background)
- Schedule:

**Schedule**

| | |
|---|---|
| 2008: | Hut construction<br>Crystals production |
| 2009: | Utilities<br>Clean room<br>External Shielding<br>Cryostat Installation and commissioning |
| 2010: | Detector assembly<br>Faraday Cage<br>Front-end & DAQ |
| 2011: | Data taking |

# SuperNEMO: foils + tracking

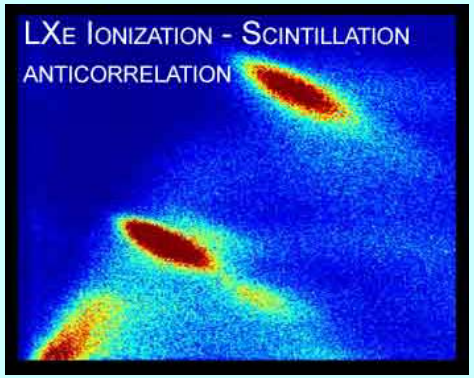
- Continuation of technoloby of NEMO3
- Flexibility on choice of isotope. Focus on $^{82}$Se and $^{150}$Nd.
- Planar and modular design.
- Planned 20 modules x 5 kg = 100 kg.
- Topology signature.
- R&D to improve energy resolution and radiopurity of foils.
- Expected sensitivity ~100 meV.

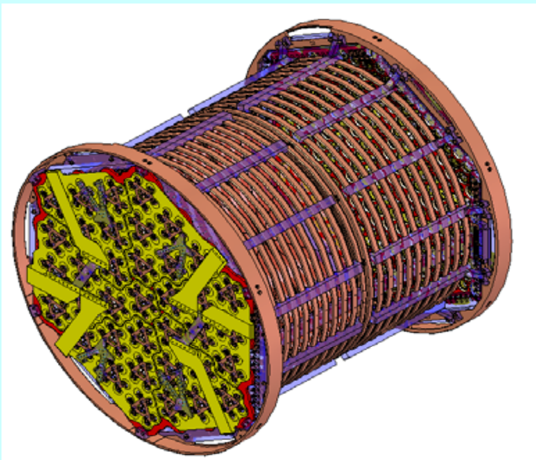


| NEMO-3 | | SuperNEMO |
|---|---|---|
| $^{100}$Mo | isotope | $^{82}$Se - baseline ($^{150}$Nd if it can be enriched) |
| 7 kg | isotope mass M | 100-200 kg |
| 18 % | efficiency ε | ~ 30 % |
| $^{208}$Tl: < 20 μBq/kg<br>$^{214}$Bi: < 300 μBq/kg | internal contaminations<br>$^{208}$Tl and $^{214}$Bi in the ββ foil | $^{208}$Tl ≤ 2 μBq/kg<br>*if $^{82}$Se:* $^{214}$Bi ≤ 10 μBq/kg |
| 8% @ 3MeV | energy resolution (FWHM) | 4% @ 3 MeV |
| $T_{1/2}(0\nu\beta\beta) > 2 \times 10^{24}$ y<br>$<m_\nu> < 0.3$ 0.9 eV | | $T_{1/2}(0\nu\beta\beta) > 10^{26}$ y<br>$<m_\nu> < 0.04 - 0.11$ eV |

# EXO: Xenon TPCs

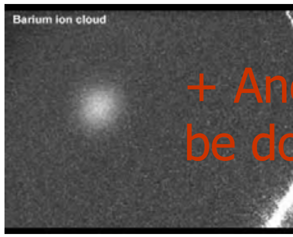
- EXO experiment:
  - Liquid Xe TPC
  - Energy measurement by ionization + scintillation
  - No single e- identification → poor background rejection
  - R&D for Ba ion tagging in progress (136Xe → 136Ba++ + 2e-)
  - EXO200 being commissioned at WIPP, without Ba tagging



Liquid vs. Gas

| Liquid Xe | | Gas Xe |
|---|---|---|
| ✓ | Scalability | ✓ |
| ✓ | Compact | ✗ |
| Cryogenics | Complexity | High P |
| ✗ | Topology | ✓ |
| ✓ | E resolution | ✓ |




+ And Ba tagging can be done better in gas

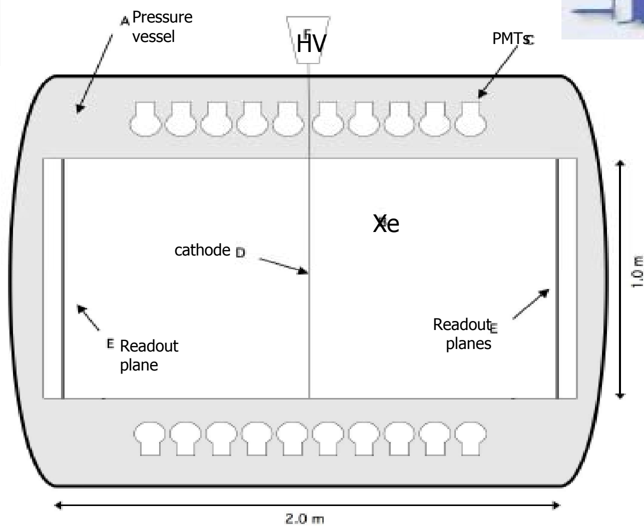
# A new initiative: NEXT

...at Canfranc

- A **N**eutrino **E**xperiment with a gas **X**e **T**PC may:

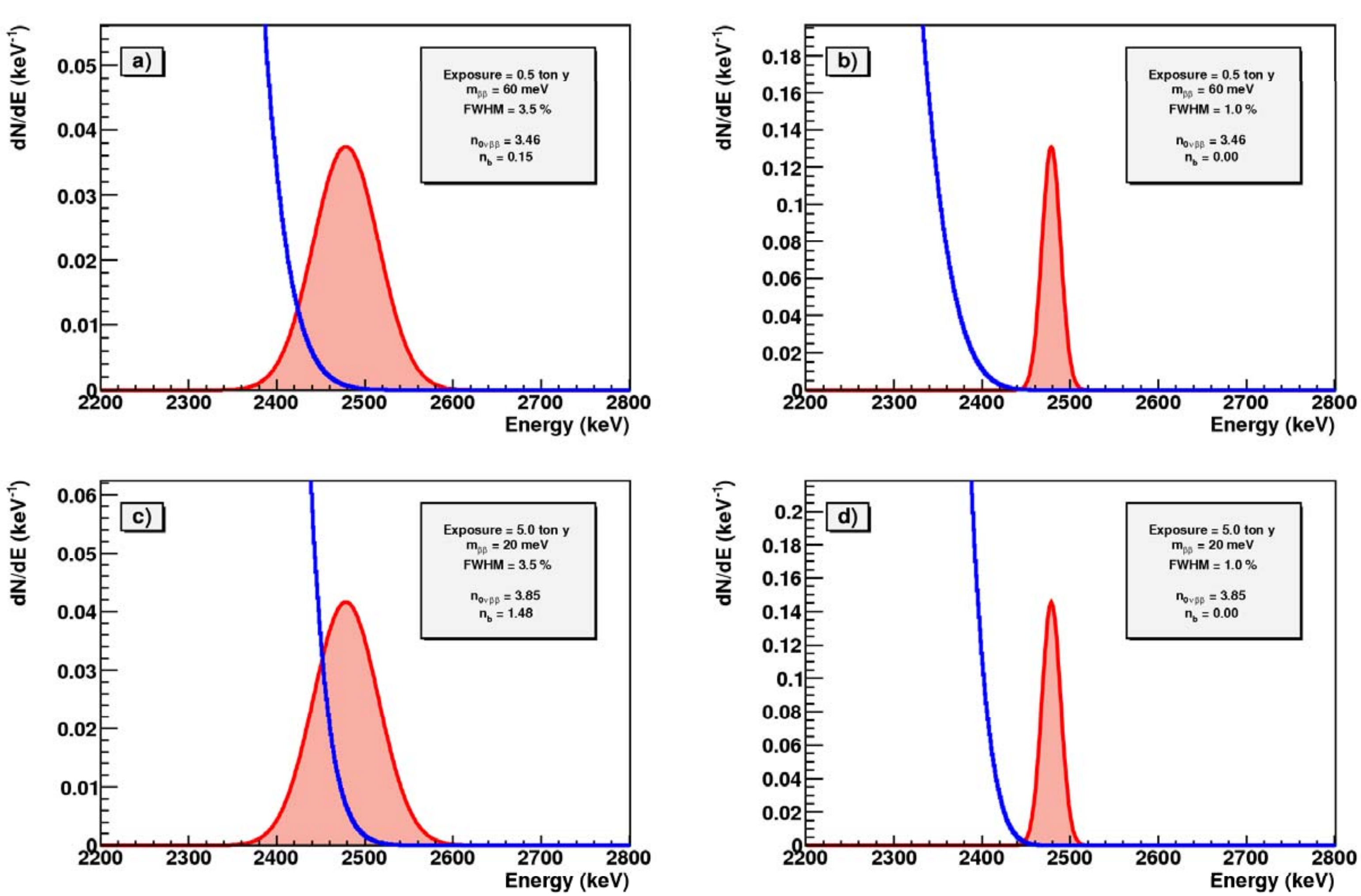
1. Have all advantages of a Xe monolithic detector (like EXO)
2. Outdo Liquid Xe by getting topological info
3. Override tradicional limitation of gas TPCs (Gothard) by applying the latest developments on TPC readouts

- Competitive option for the next (ton scale) generation of experiments



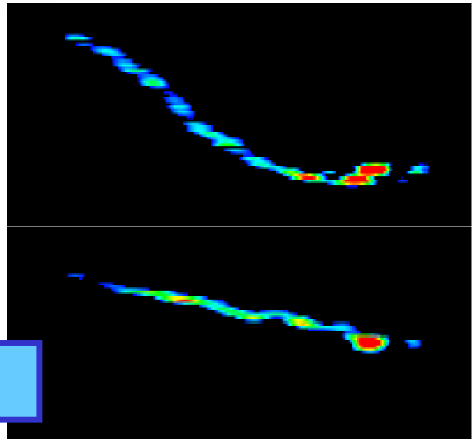

Initiative pushed by spanish groups *(Barcelona, Ciemat, Santiago, Valencia, Zaragoza)* for 100 kg prototype construction in Canfranc. Interest and support by other groups. Especially *Saclay (Y. Giomataris), Berkeley (D. Nygren), Canadian groups, Coimbra*, …

# The role of E resolution @ the ton scale



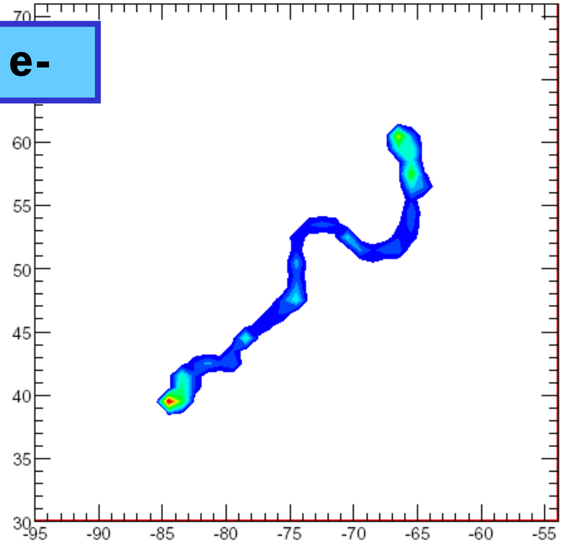
# The topological signature

- A gas TPC have access to the "image" of the event.
- 1 $e^-$ events and 2 $e^-$ events have different topologies. This can be used to reject gamma background (1 $e^-$)
- Gothard demostrated that this can be done. They achieved a 96.5% efficiency in rejecting single $e^-$ events. We may do better.
- **A gas TPC would have an extra handle to reduce background by a factor of at least 10² (most probably more?).**



1 e-

2 e-



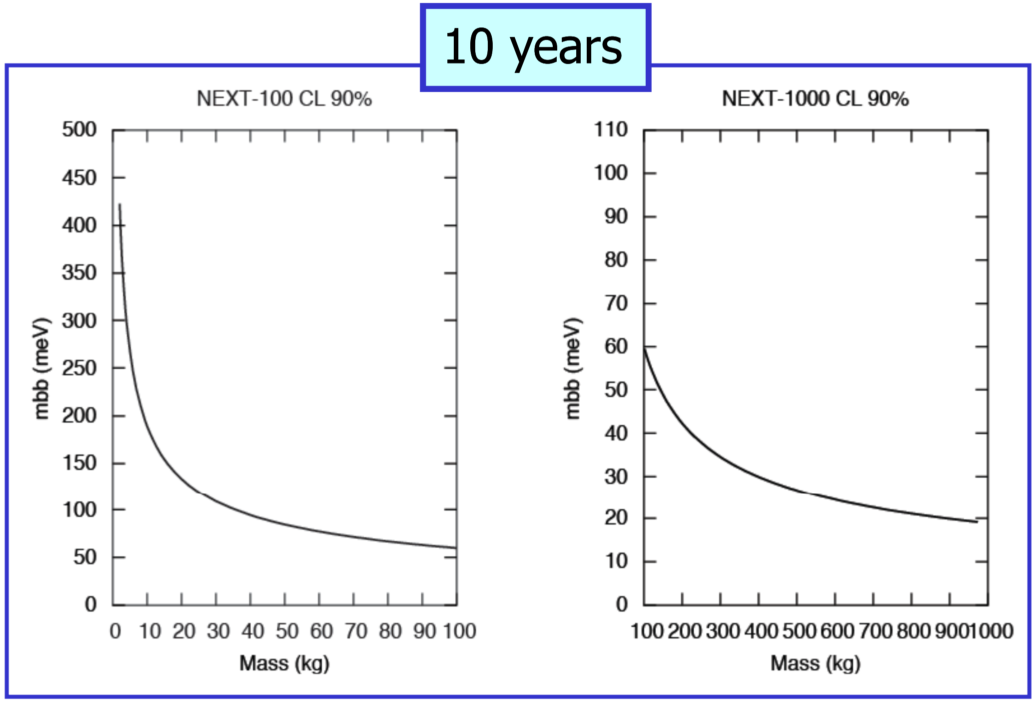
# NEXT

- A sensitivity down to 60 eV (for NEXT-100) and 20 eV (for NEXT-1000) is a priori reachable:

Of course, IF

- Low enough resolution is achieved (~1% FWHM)
- Low enough backgroung after topology cuts (i.e. not background limited)

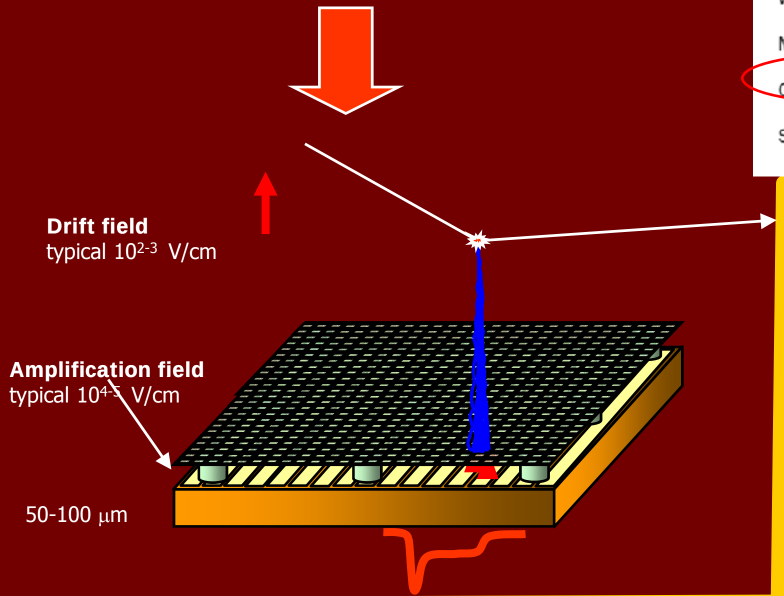
- We believe this is possible after last developments on TPC
- NEXT is on the way to demonstrate these issues (as well as other technical ones)
- Very encouraging first steps

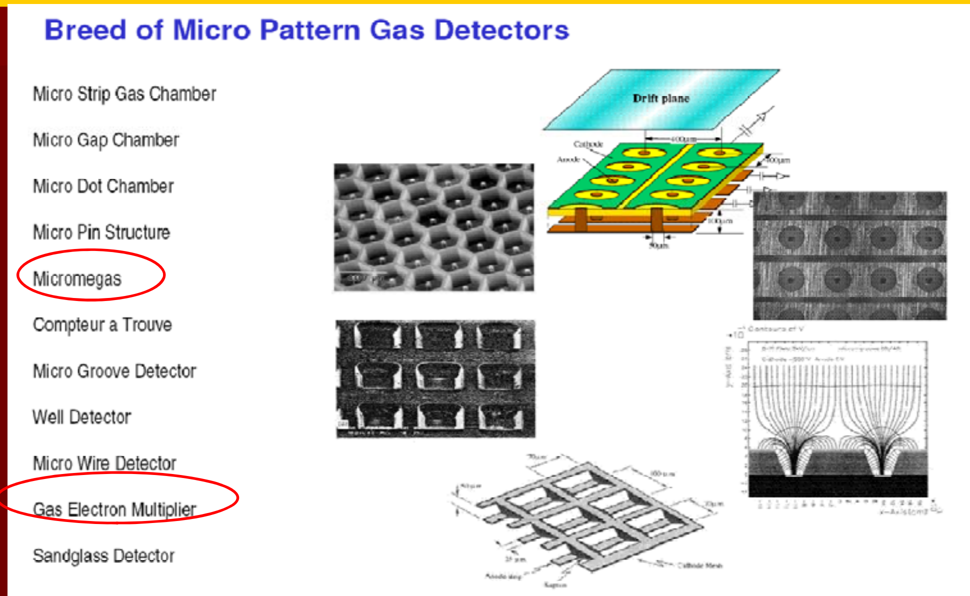


# Novel concepts on TPC readouts

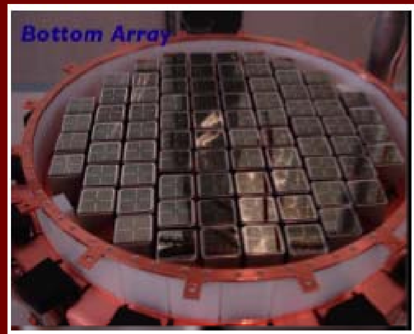
Micropattern detectors:
seminal idea is atributed to
Oed (88)

**e.g. MICROMEGAS**
Giomataris, Charpak (96)




Gas Proportional Scintillation Counter (XENON dark matter exp.)



# Expresion of Interest to Canfranc

Expression of Interest to the Canfranc Scientific Committee

## NEXT: A proposed Neutrino Experiment with a Xenon TPC

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Lawrence Berkeley Laboratory, Berkeley, USA

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CEA/Saclay, Paris, France

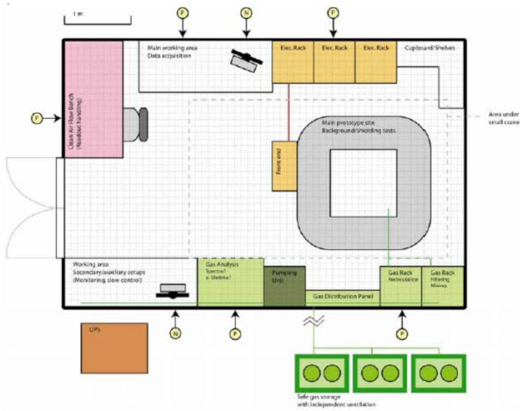
M. Ball, J. Catala, A. Cervera, J. Díaz, A. Gil, J. J. Gómez-Cadenas,
C. Hansen, J. Martín-Albo, F. Monrabal, L. Monfregola,
J. Muñoz-Vidal, P. Novella, M. Sorel, N. Yahlali
Instituto de Física Corpuscular, IFIC, CSIC - U. Valencia, Spain

R. Bravo, R. Palma, J. L. Pérez, R. Ripoll
U. Politécnica de Valencia, Spain

J. M. Carmona, S. Cebrián, Th. Dafni , J. Galn, H. Gómez,
F. J. Iguaz, I. G. Irastorza, G. Luzón, J. Morales,
A. Rodríguez, J. Ruz, A. Tomás, J. A. Villar
U. Zaragoza, Spain

EoI approved by LSC scientific committee on April08

- Footprint of 30 m2 area requested to LSC to perform R&D and operate the prototype NEXT10



- 100 m2 in the hall A is anticipated for the construction of the NEXT100 detector

NEXT enjoyed funding (~4 M€) from the CONSOLIDER program as part of the **CUP** (Canfranc Underground Physics) proprosal, approved in the 2008 call

# Expected NEXT roadmap

Funded by CUP CONSOLIDER

| NEXT10 phase<br>Up to 2011 | NEXT100 detector<br>Up to 2013 | Large scale<br>Beyond 2013 |
|---|---|---|
| ■ R&D activities:<br>– E resolution, t0, radiopurity, backgrounds, etc…<br>–NEXT0 prototypes at institutions<br>■ Small scale (10 kg) demonstrating prototype underground **NEXT10**<br>■ Conceptual design of NEXT100 fixed | ■ Construction of larger prototype with physics interest NEXT100 at Canfranc:<br>- about 100 kg<br>■ Continued R&D for further scaling up:<br>– Backgrounds<br>– Ba++ tagging ? | ■ Final detector (ton scale and beyond) |

# Future of $0\nu\beta\beta$ searches

- Goal of present projects: ~100 kg of target mass ($<m_{\beta\beta}>$=50-150 meV). Check KKDC claim.
- Next generation: **few ton scale**. Down to 10-20 meV. Fully explore inverse hierarchy mass models
- Energy resolution at the 1% FWHM level at least.
- Backgrounds down to $10^{-4} - 10^{-5}$ c/keV/kg/y.
- Signal must be seen in several isotopes.
- ASPERA: 2 big experiments in Europe.
- Nice prospects for Canfranc to be well in the quest for $0\nu\beta\beta$

# Conclusions

- **Underground Labs** are the needed environment for high sensitvity Rare Event  Searches, like DM and DBD. They have become a *key facility in modern astroparticle physics*.
- Dark Matter:
  - **Growing observational evidence** (cosmological, astrophysical).
  - Suspicious results in direct (DAMA) and indirect (PAMELA, ATIC,…)
  - **Many groups + increased activity**. Recent WIMP limits from XENON10 and CDMS (and several others)
  - Don´t forget the axion!
- Double Beta Decay:
  - Also suspicious signal here!
  - **Leading experiments** in Europe (CUORE, GERDA, SN) and US (EXO), are exploring complementary strategies towards the 100 kg scale.
  - **NEXT** in Canfranc is the most recent proposal, very promising alternative, specially for next 1-ton generation.
- **Exciting** times for the field!!!