Ricerche Dirette di Materia Oscura



P. Belli INFN – Roma Tor Vergata Pomeriggio di Discussione su Materia Oscura, INFN, Roma, 20 Gennaio 2014

Relic DM particles from primordial Universe

SUSY

(as neutralino or sneutrino in various scenarios)

the sneutrino in the Smith and Weiner scenario

sterile v

electron interacting dark matter

a heavy v of the 4-th family $\hat{}$

even a suitable particle not yet foreseen by theories axion-like (light pseudoscalar and scalar candidate)

self-interacting dark matter

mirror dark matterKaluza-Klein particles (LKK)

heavy exotic canditates, as "4th family atoms", ...

Elementary Black holes, Planckian objects, Daemons

invisible axions, ν 's

etc...



Moreover, several questions arise about:

- interaction type with ordinary matter and its description
- related nuclear and particle physics
- halo model and parameters
- halo composition. DM multicomponent also in the particle sector?
- non thermalized components?
- caustics?
- clumpiness?
- etc.



What accelerators can do:

to demostrate the existence of some of the possible DM candidates

What accelerators cannot do:

to credit that a certain particle is the Dark Matter solution or the "single" Dark Matter particle solution...

 DM candidates and scenarios exist (even for neutralino candidate) on which accelerators cannot give any information

DM direct detection method using a model independent approach and a lowbackground widely-sensitive target material



Some direct detection processes:



Dark Matter direct detection activities in underground labs

- Various approaches and techniques
- Various different target materials
- Various different experimental site depths
- Different radiopurity levels, etc.
- Gran Sasso (depth ~ 3600 m.w.e.): DAMA/Nal, DAMA/ LIBRA, DAMA/LXe, HDMS, WARP, CRESST, Xenon, Dark Side
- Boulby (depth ~ 3000 m.w.e.): Drift, Zeplin, NAIAD
- Modane (depth ~ 4800 m.w.e.): Edelweiss
- Canfranc (depth ~ 2500 m.w.e.): ANAIS, Rosebud, ArDM





- Stanford (~10 m): CDMS I
- Soudan (~ 2000 m.w.e.): CDMS II, CoGeNT, COUPP (also FNAL)
- DUSEL (~4400 m.w.e.): LUX
- WIPP (~1600 m.w.e.): DMTPC

South Pole: DM-ICE





- Y2L (depth ~ 700 m): KIMS
- Oto (depth ~ 1400 m.w.e.): PICO-LON
- Kamioka (depth ~2700 m.w.e.): XMASS, NEWAGE

Direct detection experiments

The direct detection experiments can be classified in **two classes**, depending on what they are based:



- on the recognition of the signals due to Dark Matter particles with respect to the background by using a model-independent signature
- 2. on the use of uncertain techniques of statistical **subtractions** of the e.m. component **of the counting rate** (adding systematical effects and lost of candidates with pure electromagnetic productions)



Experiments using liquid noble gases

- Single phase: LXe, LAr, LNe \rightarrow scintillation, ionization
- Dual phase liquid /gas \rightarrow prompt scintillation + secondary scintillation

Statistical rejection of e.m. component of the counting rate

in single phase detector:

 pulse shape discrimination γ/recoils from the UV scintillation photons





DAMA/LXe

XMASS

DAMA/LXe: low background developments and applications to dark matter investigation (since N.Cim. A 103 (1990) 767)

in dual phase detector:

- prompt signal (S1): UV photons from excitation and ionization
- delayed signal (S2): e- drifted into gas phase and secondary scintillation due to ionization in electric field



XENON10, 100, WARP, Dark Side, LUX

but e.g. UV light, disuniformity, self-absorption, unlinearity in large volumes

Examples of energy resolutions



(upper) and S2 spectrum (lower). The fits are double Gaussian fits which incorporate both the 122 keV and 136 keV lines in the 57 Co γ -ray spectrum. The energy resolution of the detector is derived from the width of the S1 peak, coupled with calibration measurements at other line energies.

JoP: Conf. Ser. 65 (2007) 012015

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XENON100 results



Experimenta Target mate Target mass: Used exposu

- Non-uniform response of detector: intrinsic limit
- Correction procedures applied
- Systematics
- Small light responses (2.2 ph.e./ $keVee) \Rightarrow$ energy threshold at few keV unsafe
- Physical energy threshold unproved by source calibrations
- Poor energy resolution; resolution at threshold **unknown**
- Light responses for electrons and recoils at low energy
- Quenching factors measured with c much more performing detector cannot be used straightforward

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tion between e⁻/γ and nuclear ulations are quite overlapped.

> pplied, each of them can stematics. The systematics able along the data taking they and the related oe suitably evaluated in calibration?



• Etc.

For example: what about the response of LXe set-ups at low-energy recoils?

Remind: open question about the real energy threshold

- A low mass WIMP (7 GeV) can induce a maximum recoil energy of 4 keVr to a Xe nucleus: 90% of the events are below 1.5 keVr.
- Tail distribution is more sensitive to the experimental (small number of ph.el./keV, small energy resolution, stability of the energy scale, stability of all the selection windows, ...) and theoretical (models, parameters, such as escape velocity, form factors, ...) uncertainties
- $\rm L_{eff}$ is assumed by XENON-100 either constant at 0.12 below 10 keVr or extrapolated. But this is not the case.
 - L_{eff} drastically drops at lower energy?
 - Kinematic cutoff?
 - More precise measurements and/ or more reliable theoretical evaluations required.

The measurements must be performed in the same set-up used for the DM search

1106.0653: "A lingering critical question is to what extent a determination of L_{eff} performed using highly-optimized compact calibration detectors like those in ... can be applied with confidence to a much larger device like the XENON100 detector, featuring a small S1 light-detection efficiency (just ~6%), different hardware trigger configuration, data processing, etc."



All this yields to overstimate the sensitivity and to achieve too optimistic exclusion plots

see also: arXiv:1005.0838, 1006.2031, 1005.3723, 1010.5187, 1106.0653, 1104.2587

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Recent results from LUX

arXiv:1310.8214



Experimental site: Sanford Underground Research Facility (SURF, 4300 m.w.e.)

Target:

370 kg LXe (≈250 kg dual phase actively monitored) fiducial volume (118.3±6.5) kg

Live time:

85.3 days

Experimental approach: statistical discrimination between electrons (e^{γ}/γ) and nuclear recoils. The two

- Response: 8.8 phe/keV_{ee} at 122 keV (and at low energy ?)
- Analysis applied after data cuts (''high'' acceptance ?)
- Data events subtractions (efficiency ?)
- WIMP \$1 and \$2 expected reference distributions obtained by simulations
- Threshold: 2 phe \approx 3 keV_r (!?)
- 160 events after the cuts

All NR band events assumed to be due to ER bkg events

(0.64 ± 0.16) ER events expected below NR mean It confirms that the two populations are quite overlapped



 $\begin{array}{c} \mbox{ER band ($\pm 1.28 \sigma$)$} \\ \mbox{NR band ($\pm 1.28 \sigma$)$} \\ \mbox{Approx. location of the minimum S2 cut} \end{array}$

Results from double read-out bolometric technique (ionization vs heat)

Experimental site:

Set-up:

Target: Exposure:

Approaches: Neutron shield: Quenching factor:



PRL102,011301(2009), arXiv:0912.3592

CDMS-II

Soudan

19 Ge detectors (≈ 230 g) + 11 Si detectors (100 g) , only 10 Ge detectors used in the data analysis 3.22 kg Ge 194.1 kg x day

nuclear recoils + subtraction 50 cm polyethylene assumed 1



Edelweiss II

Lab. Souterrain de Modane (LSM) (4800 m.w.e., 4 μ /m²/day) 3.85 kg Ge (10 Ge ID detectors, 5 x 360 g, 5 x 410 g),

natGe fiducial volume = 2.0 kg 384 kg x day (2 periods: July-Nov 08, April 09-May 10) nuclear recoils + subtraction 30 cm paraffin assumed 1 • 85% live time ("regular



- 85% live time ("regular maintenance and unscheduled stops")
- 16 days devoted to γ and n calibration
- 17% reduction of exposure for run selection

5 events observed (4 with E<22.5keV_{recoil}; 1 with E=172keV_{recoil})

PLB702,5 (2011) 329

Data selection, handling and e.m. rejection procedures CDMS-II





Event Selection: Veto-anticoincidence cut Single-scatter cut WQinner (fiducial volume) cut us performed on parameter distributions. Our deter Ionization yield cut Phonon timing cut from arXiv: 0912.3592

Data reduction and selection:

- poor detector performances, many detectors excluded in the analysis some other detectors excluded in subsets, etc.
- critical stability of the performances

scatters. Five Ge detectors were not used for WIM tection because of poor performance or insufficient ca ration data; four more detectors were similarly excluded uring subsets of the four periods. We excluded Si deteoors in this analysis due to their lower sensitivit coherent nuclear elastic scattering

subset of events were analyzed to monitor tector stability and identify periods of poor detector performance. Data quality criteria were developed on

tors require regular neutralization [15] to maintain full ionization collection. We monitor the yield distribution and remove periods with poor ionization collection. After these data quality selections, the total exposure to WIMPs considered for this work was 612 kg-days.

Phonon timing cut: time and energy response vary across the detector \Rightarrow look-up table used (stability, robustness of the reconstruction procedure, efficiency and uncertainties)

... comments

- Strong data selection (some detectors excluded in the analysis, some other detectors excluded in subsets, ..., poor detectors performance)
- Many cuts on the data: how about systematics? The systematics can be variable along the data taking period; can they and the related efficiencies be suitably evaluated in short period calibration?
- Knowledge and control of "physical" energy threshold, energy scale, Y scale, quenching factor, sensitive volumes, efficiencies, ...? + stability with time of all these quantities?
- Efficiencies of cuts and of coincidence of the ionized and heat signals
- Due to small number of events to deal after selection, even small fluctuations of parameters (energy, Y scales, noises, ...) and of tails of the distributions can play a relevant role
- Not uniform detector responses vs surface electrons

Final results from CDMS – Si

arXiv:1304.3706 arXiv:1304.4279

6

8

Results of CDMS-II with the Si detectors published in two close-in-time data releases:



candidates survive in an exposure of 140.2 kg x day. Estimated residual background 0.41

> A profile likelihood analysis favors a signal hypothesis at 99.81% CL (~ 3σ , p-value: 0.19%).

0 2 4 Normalized Timing

-2

Positive hint from CRESST (scintillation vs heat)

Experimental site: Detector:

Gran Sasso (LNGS) 33 CaWO₄ crystals (10 kg mass) data from 8 detectors

Exposure:

≈ 730 kg x day

Discrimination of nuclear recoils from radioactive backgrounds by simultaneous measurement of phonons and scintillation light

Data from one detector



Future Run with improvement in preparation



Likelihood Analysis

	M1	M2
e /γ-events	8.00 ± 0.05	8.00 ± 0.05
a-events	11.5 ^{+2.6}	11.2+2.5
neutron events	7.5 ^{+6.3}	9.7 +6.1
Pb recoils	15.0 +5.2	18.7 +4.9
signal events	29.4 +8.6	24.2+8.1
n _x [GeV]	25.3	11.6
J ^{WN} [bb]	1.6 · 10 - 5	3.7 · 10-5
stat. significance	4.7 σ	4.2 σ

background-only hypothesis rejected with high statistical significance → additional source of events needed (Dark Matter?) Efficiencies + stability + calibration, crucial role

Positive hints from CoGeNT (ionization detector)

Experimental site: Detector:

Soudan Underground Laboratory (2100 mwe)

440 g, p-type point contact (PPC) Ge diode 0.4 keVee energy threshold 146 kg x day (dec '09 - mar '11)

Exposure:





PRL107(2011)141301

data cut applied No Statistical rejection of e.m. component of the



✓ Irreducible excess of bulk-like events below 3 keVee observed; \checkmark annual modulation of the rate in 0.5-3 keVee at ~2.8 σ C.L.

In data taking since July 2011 after the fire in Soudan

New data from COGENT



persistent annual modulation exclusively at low energy and for bulk events. Best-fit phase consistent with DAMA/LIBRA (small offset may be meaningful). Similar best-fit parameters to 15 mo dataset, but with much better bulk/surface separation (~90% SA for~90% BR)

 Unoptimized frequentist analysis yields ~2.2σ preference over null hypothesis. This however does not take into account the possible relevance of the modulation amplitude found...

& also excess of recoil-like events with respect to estimated backgrounds surviving the cuts applied by those expts: CRESST 4 σ C.L. effect, CDMS marginal (exposures orders of magnitude lower than DAMA)



Even very small **systematics** in the data selections and statistical discrimination and rejection procedures can be difficult to estimate; **e.m. component** of the rate can contain the signal or part of it

Even assuming pure recoil case and ideal discrimination on an event-byevent base, the result will NOT be the identification of the presence of WIMP elastic scatterings as DM signal, because of the well **known existing recoil-like indistinguishable background**

Therefore, even in the ideal case the "excellent suppression of the e.m. component of the counting rate" can **not** provide a "signal identification"

A model independent signature is needed

Directionality Correlation of Dark Matter impinging direction with Earth's galactic motion due to the distribution of Dark Matter particles velocities



Diurnal modulation Daily variation of the interaction rate due to different Earth depth crossed by the Dark Matter particles

only for high $\boldsymbol{\sigma}$

some DM candidates

very hard to realize, it holds for

Annual modulation Annual variation of the interaction rate due to Earth motion around the Sun at present the only feasible one, sensitive to many DM candidates and scenarios



The annual modulation: a model independent signature for the investigation of DM particles component in the galactic halo

With the present technology, the annual modulation is the main model independent signature for the DM signal. Although the modulation effect is expected to be relatively small a suitable large-mass, low-radioactive set-up with an efficient control of the running conditions can point out its presence.

Requirements of the annual modulation

- 1) Modulated rate according cosine
- 2) In a definite low energy range
- 3) With a proper period (1 year)
- 4) With proper phase (about 2 June)
- 5) Just for single hit events in a multidetector set-up
- 6) With modulation amplitude in the region of maximal sensitivity must be <7% for usually adopted halo distributions, but it can be larger in case of some possible scenarios



the DM annual modulation signature has a different origin and peculiarities (e.g. the phase) than those effects correlated with the seasons

To mimic this signature, spurious effects and side reactions must not only - obviously - be able to account for the whole observed modulation amplitude, but also to satisfy contemporaneously all the requirements

The DAMA/LIBRA set-up ~250 kg NaI(Tl) (Large sodium Iodide Bulk for RAre processes)



As a result of a 2nd generation R&D for more radiopure Nal(Tl) by exploiting new chemical/physical radiopurification techniques (all operations involving - including photos - in HP Nitrogen atmosphere)



Residual contaminations in the new DAMA/LIBRA Nal(TI) detectors: ²³²Th, ²³⁸U and ⁴⁰K at level of 10⁻¹² g/g







Radiopurity, performances, procedures, etc.: NIMA592(2008)297, JINST 7 (2012) 03009

Results on DM particles, Annual Modulation Signature: EPJC56(2008)333, EPJC67(2010)39, EPJC73(2013)2648.
Related results: PRD84(2011)055014, EPJC72(2012)2064, IJMPA28(2013)1330022

Results on rare processes: PEP violation: EPJC62(2009)327; CNC in I: EPJC72(2012)1920; IPP in ²⁴¹Am decay: EPJA49(2013)64

Model Independent Annual Modulation Result DAMA/Nal + DAMA/LIBRA-phase1 Total exposure: 487526 kg×day = 1.33 ton×yr



The data favor the presence of a modulated behaviour with all the proper features for DM particles in the galactic halo at about 9.2σ C.L.

Model Independent Annual Modulation Result DAMA/Nal + DAMA/LIBRA-phase1 Total exposure: 487526 kg×day = 1.33 ton×yr

EPJC 56(2008)333, EPJC 67(2010)39, EPJC 73(2013)2648



- No modulation above 6 keV
- No modulation in the whole energy spectrum
- No modulation in the 2-6 keV multiple-hit events

No systematics or side processes able to quantitatively account for the measured modulation amplitude and to simultaneously satisfy the many peculiarities of the signature are available.

- Compatibility with many low and high mass DM candidates, interaction types and astrophysical scenarios, and in particular with recent positive model dependent hints from direct or indirect searches
- No other experiment exists whose result can be at least in principle directly compared in a model-independent way with those by DAMA/Nal & DAMA/LIBRA-phase1

Just few examples of interpretation of the annual modulation in terms of candidate particles in some scenarios



Compatibility with several candidates; other ones are open



Features of the DM signal

The importance of studying second order effects and the annual modulation phase



A step towards such investigations: DAMA/LIBRA-phase2

with lower energy threshold and larger exposure + further possible improvements (DAMA/LIBRA-phase3) and DAMA/1ton

DAMA vs possible positive hints 2010 - 2013

CoGeNT:

low-energy rise in the spectrum ("irreducible" by the applied background reduction procedures) + annual modulation









after many data selections and cuts, 2 Ge recoil-like candidates survive in an exposure of 194.1 kg x day (0.8 estimated as expected from residual background)

<u>CRESST</u>: after many data selections and cuts, 67 recoil-like candidates in the O/Ca bands survive in an exposure of 730 kg x day (expected residual background: 40-45 events, depending on minimization)

TIZI

10/27/07

T3Z4 08/05/07 9 50 60 roll Energy (Jary)





CDMS-Si:

after many data selections and cuts, 3 Si recoil-like candidates survive in an exposure of 140.2 kg x day. Estimated residual background 0.41

All those recoil-like excesses with respect to an estimated bckg surviving cuts as well as the CoGeNT result are compatible with the DAMA 9.3 σ C.L. annual modulation result in various scenarios



...models...

- Which particle?
- Which interaction coupling?
- Which Form Factors for each target-material?
- Which Spin Factor?
- Which nuclear model framework?
- Which scaling law?
- Which halo model, profile and related parameters?
- Streams?
- ...

About interpretation

See e.g.: Riv.N.Cim.26 n.1(2003)1, JMPD13(2004)2127, EPJC47(2006)263, IJMPA21(2006)1445, EPJC56(2008)333, PRD84(2011)055014, IJMPA28(2013)1330022

- ...and experimental aspects...
- Exposures
- Energy threshold
- Detector response (phe/keV)
- Energy scale and energy resolution
- Calibrations
- Stability of all the operating conditions.
- Selections of detectors and of data.
- Subtraction/rejection procedures and stability in time of all the selected windows and related quantities
- Efficiencies
- Definition of fiducial volume and nonuniformity
- Quenching factors, channeling, ...

Uncertainty in experimental parameters, as well as necessary assumptions on various related astrophysical, nuclear and particle-physics aspects, affect all the results at various extent, both in terms of exclusion plots and in terms of allowed regions/volumes. Thus comparisons with a fixed set of assumptions and parameters' values are intrinsically strongly uncertain.

No experiment can be directly compared in model independent way with DAMA

Examples of uncertainties in models and scenarios

Nature of the candidate and couplings

- •WIMP class particles (neutrino, sneutrino, etc.): SI, SD, mixed SI&SD, preferred inelastic + e.m. contribution in the detection
- Light bosonic particles
- Kaluza-Klein particles
- Mirror dark matter
- Heavy Exotic candidate
- •...etc. etc.

Scaling laws of cross sections for the case of recoiling nuclei

• Different scaling laws for different DM particle:

σ_A∝μ²**Α²(1+**ε_A)

 $\varepsilon_A = 0$ generally assumed

 $\epsilon_A \approx \pm 1$ in some nuclei? even nucleus interaction for neutralino candidate in MSSM (see Prezeau, Kamionkowski, Vogel et al., PRL91(2003)231301) In SD form factors: decoupling between and Dark Matter particular degrees of freedom

Halo models & Astrophysical scenario

- Isothermal sphere ⇒ very simple but unphysical halo model
- Many consistent halo models with different density and velocity distribution profiles can be considered with their own specific parameters (see e.g. PRD61(2000)023512)
- Caustic halo model

Form Factors for the case of recoiling nuclei

- Many different profiles available in literature for each isotope
- Parameters to fix for the considered profiles
- Dependence on particlenucleus interaction
- In SD form factors: no decoupling between nuclear and Dark Matter particles degrees of freedom + dependence on nuclear potential

Presence of nonthermalized DM particle components

- Streams due e.g. to satellite galaxies of the Milky Way (such as the Sagittarius Dwarf)
- Multi-component DM halo
- Clumpiness at small or large scale
- Solar Wakes
- •....etc. ...

Spin Factors for the case of recoiling nuclei

- Calculations in different models give very different values also for the same isotope
- Depend on the nuclear potential models
- Large differences in the measured counting rate can be expected using:

either SD not-sensitive isotopes

or SD sensitive isotopes depending on the unpaired nucleon (compare e.g. odd spin isotopes of Xe, Te, Ge, Si, W with the ²³Na and ¹²⁷I cases).

see for some details e.g.:

Riv.N.Cim.26 n.1 (2003) 1, IJMPD13(2004)2127, EPJC47 (2006)263, IJMPA21 (2006)1445

Instrumental quantities

- Energy resolution
- Efficiencies
- Quenching factors
- Channeling effects
- Their dependence on energy

•...

Quenching Factor

- differences are present in different experimental determinations of *q* for the same nuclei in the same kind of detector depending on its specific features (e.g. *q* depends on dopant and on the impurities; in liquid noble gas e.g.on trace impurities, on presence of degassing/ releasing materials, on thermodynamical conditions, on possibly applied electric field, etc); assumed 1 in bolometers
- channeling effects possible increase at low energy in scintillators (dL/dx)

possible larger values of *q* (AstropPhys33 (2010) 40)

 \rightarrow energy dependence

... an example in literature...

Case of DM particles inducing elastic scatterings on target-nuclei, SI case



... an example in literature...

Case of DM particles inducing elastic scatterings on target-nuclei, SI case



Regions in the nucleon cross section vs DM particle mass plane

... a recent conjecture ...

arXiv:1401.3295

- Non-Maxwellian halo model is considered.
- The DAMA regions are for both Maxwellian and non-Maxwellian halo models.
- Na quenching factor taken at the fixed value 0.3
- A fractional modulation amplitude corresponding to that found for CoGeNT data is assumed for DAMA.
- For CoGeNT a fixed value for the Ge quenching factor and a Helm form factor with fixed parameters are assumed.
- The CoGeNT region includes configurations whose likelihoodfunction values differ more than 1.64 σ from the null hypothesis (absence of modulation). This corresponds roughly to 90% C.L. far from zero signal.

nium data [69] would be insensitive to up to a 100% modulation amplitude in a possible CDMS-Ge signal [63]. Liquid xenon (LUX, XENON-100) sensitivity to $m_{\chi} < 12 \text{ GeV/c}^2$ is presently under test, using an ⁸⁸Y/Be neutron source [61].



Another example of compatibility

DM particle with preferred inelastic interaction

In the Inelastic DM (iDM) scenario, WIMPs scatter into an excited state, split from the ground state by an energy comparable to the available kinetic energy of a Galactic WIMP.

δ(keV)

DAMA/Nal+DAMA/LIBRA Fund. Phys. 40(2010)900 Slices from the 3-dimensional allowed volume



iDM interaction on lodine nuclei

iDM interaction on TI nuclei of the NaI(TI) dopant?

arXiv:1007.2688

- For large splittings, the dominant scattering in NaI(TI) can occur off of Thallium nuclei, with A~205, which are present as a dopant at the 10⁻³ level in NaI(TI) crystals.
- Inelastic scattering WIMPs with large splittings do not give rise to sizeable contribution on Na, I, Ge, Xe, Ca, O, ... nuclei.

... and more considering experimental and theoretical uncertainties

$$\chi^{-} + N \rightarrow \chi^{+} + N$$

- iDM has two mass states $\chi^{\scriptscriptstyle +}$, $\chi^{\scriptscriptstyle -}$ with δ mass splitting
- Kinematical constraint for iDM

$$\frac{1}{2}\mu v^2 \ge \delta \Leftrightarrow v \ge v_{thr} = \sqrt{\frac{2\delta}{\mu}}$$

Directionality technique (at R&D stage)

- Only for candidates inducing just recoils
- Identification of the Dark Matter particle by exploiting the non-isotropic recoil distribution correlated to the Earth position with to the Sun

Anisotropic scintillators: DAMA, UK, Japan

DRIFT-IId

Binesh Loomb

The DRIFT-IId detector in the Boulby Mine

The detector volume is divided by the central cathode, each half has its own multi-wire proportional chamber (MWPC) readout. 0.8 m³ fiducial volume, 10/30 Torr CF₂/CS₂ --> 139 g



Backgroud dominated by Radon Progeny Recoils (decay of ²²²Rn daughter nuclei, present in the chamber) Detection Volum Gas Energy threshold Energy resolutio Gamma-ray reje Angular resoluti



μ-PIC (Micro Pixel Chamber) is a two dimensional position sensitive gaseous detector

	Current	Plan
Detection Volume	30 × 30 × 31 cm ³	>1m ³
Gas	CF ₄ 152Torr	CF_ 30 To
Energy threshold	100keV	35keV
Energy resolution(@ threshold)	70%(FWHM)	50%(FWH
Gamma-ray rejection(@threshold)	8×10-6	1×107
Angular resolution (@ threshold)	55 * (RMS)	30° (RM

Internal radioactive BG restricts the sensitivities ∞We are working on to reduce the backgrounds!







- The "4---Shooter" 18L (6.6 gm) TPC 4xCCD, Sealevel@MIT
- moving to WIPP

NEWAGE

 Cubic meter funded, design underway

Not yet competitive sensitivity

The ADAMO project: Study of the directionality approach with ZnWO₄ anisotropic detectors Eur. Phys. J. C 73 (2013) 2276

Directionality approach: based on the study of the correlation between the Earth motion in the galactic rest frame and the arrival direction of the Dark Matter (DM) particles able to induce nuclear recoils



The dynamics of the rotation of the Milky Way galactic disc through the halo of DM causes the Earth to experience a wind of DM particles apparently flowing along a direction opposite to that of solar motion relative to the DM halo ...but, because of the Earth's rotation around its axis, the DM particles average direction with respect to an observer fixed on the Earth changes during the sidereal day



Nuclear recoils are expected to be strongly correlated with the DM impinging direction This effect can be pointed out through the study of the variation in the response of anisotropic scintillation detectors during sidereal day



Nano Imaging Tracker (NIT) emulsions





Track readout: track length ranges also $\leq \lambda$. \rightarrow use an expansion technique on the films and make a pre-selection on the optical microscopes \rightarrow use X-ray microscopy

Camera a bolle – Geyser (MOSCAB in CSN5)



20 L in construction

In both cases: technical limitations on the technique (reachable sensitivities, energy thresholds, stability, ...), just Dark Matter candidates inducing recoils, tests made at very high energy recoils, what about low energy recoils?

Altre idee fuori Italia: SIMPLE, PICASSO, COUPP; DRIFT, NEWAGE, DM-TPC, ...

Conclusions

DARK MATTER investigation with direct detection approach

- Different **solid** techniques can give complementary results
 - Some further efforts to demonstrate the **solidity** of some techniques are needed
 - Higher exposed mass not a synonymous of higher sensitivity
 - The model independent signature is the definite strategy to investigate the presence of Dark Matter particle component(s) in the Galactic halo

