Misura della risposta anisotropa di un cristallo scintillatore di $ZnWO_4$

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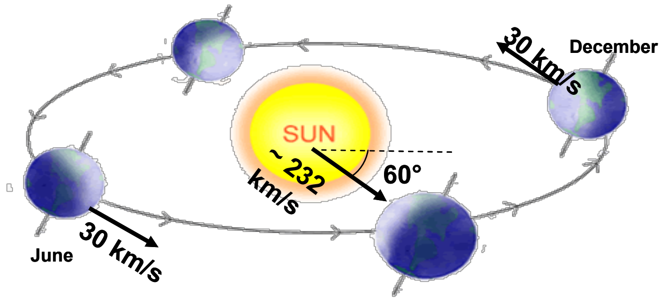
on behalf of ADAMO collaboration
University of Roma "Tor Vergata" and INFN

Signatures for direct detection experiments

In direct detection experiments to provide a Dark Matter signal identification with respect to the background a model independent signature is needed



- Model independent annual modulation: annual variation of the interaction rate due to Earth motion around the Sun which is moving in the Galaxy
  at present the only feasible one, sensitive to many DM candidates and scenarios
  (successfully exploited by DAMA)

- Model independent Diurnal modulation: due to the Earth revolution around its axis
  2nd order effect

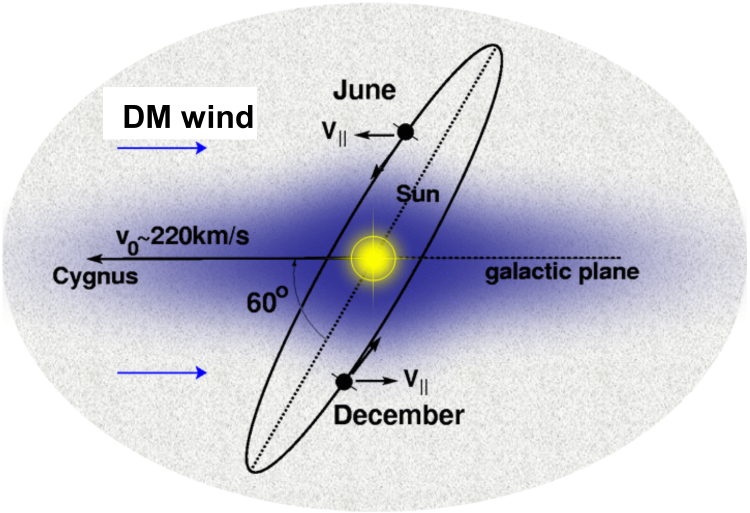
- Diurnal variation: daily variation of the interaction rate due to the different Earth depth crossed by the Dark Matter particles
  only for high cross sections

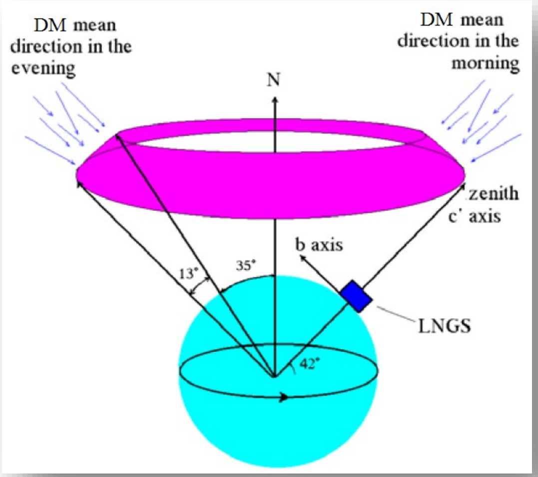
- **Directionality**: correlation of Dark Matter impinging direction with Earth's galactic motion
  only for DM candidate particle inducing recoils

What the directionality approach is?

Based on the study of the correlation between the arrival direction of those Dark Matter (DM) candidates able to induce a nuclear recoil and the Earth motion in the galactic frame

Impinging direction of DM particle is (preferentially) opposite to the velocity of the Sun in the Galaxy…





…and because of the Earth's rotation around its axis, the DM particles average direction with respect to an observer on the Earth changes with a period of a sidereal day

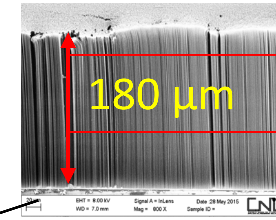
In the case of DM particles interacting with nuclei, the direction of the induced nuclear recoil is strongly correlated with that of the impinging DM particle. Therefore, the observation of an anisotropy in the distribution of nuclear recoil direction could give evidence and information for such candidates

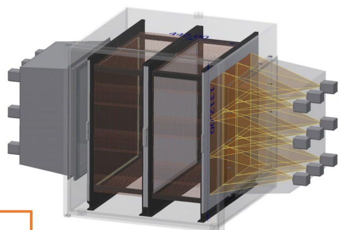
We need is a direction-sensitive detector

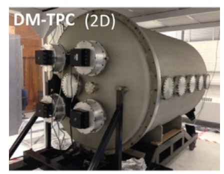
Directionality sensitive detectors

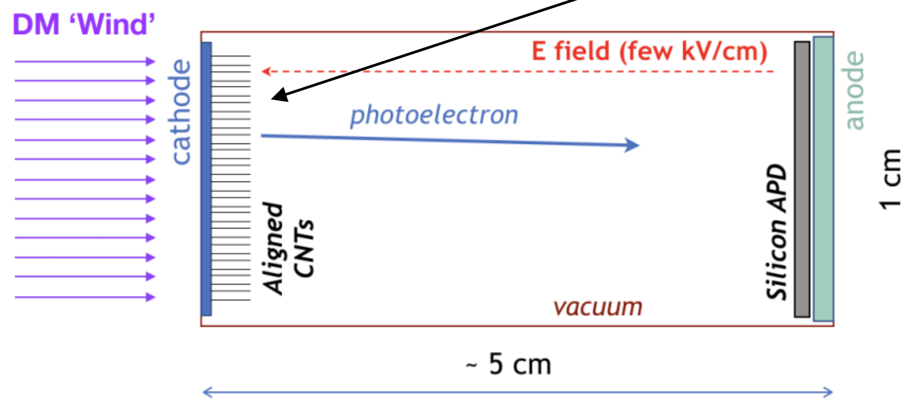
Strategies:
- Gaseous TPC (MIMAC, CYGNUS, NEWAGE, D^3,…)
- Liquid TPC (columnar recombination ?) (RED)
- Emulsion (NEWS-DM)
- Nano tube (Dark PMT)
- **Anisotropic crystals (ADAMO)**

detection of the tracks' directions









?

Low Pressure **Time Projection Chamber** might be suitable; in fact the range of recoiling nuclei is of the order of mm (while it is ~µm in solid detectors)

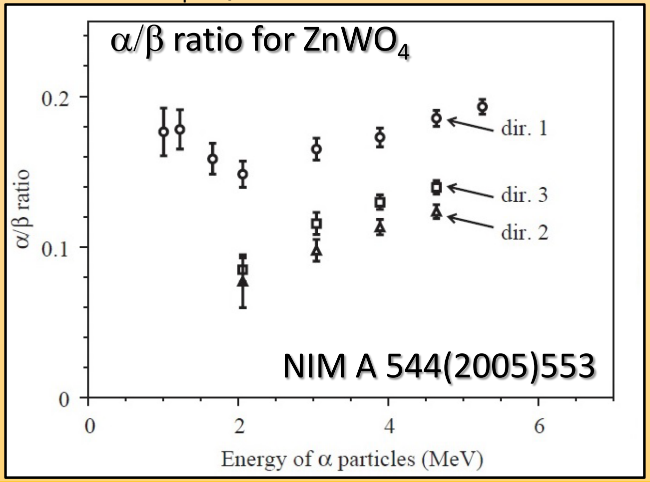
In order to reach a significant sensitivity, a realistic detector experiment needs e.g.:
- <u>**extreme operational stability**</u>
- high radio-purity
- <u>**high mass**</u>
- great spatial resolution (for tracks' detection)
- low energy threshold
- …

Directionality sensitive detectors: anisotropic scintillators

- The use of anisotropic scintillators to study the directionality signature proposed for the first time in refs. **[P. Belli et al., Il Nuovo Cim. C 15 (1992) 475]**, where the case of anthracene was analysed; some preliminary activities have been carried out [N.J.C. Spooner et al, IDM1997 Workshop; Y. Shimizu et al., NIMA496(2003)347]: the idea was revisited in [**R. Bernabei et al., EPJC28(2003)203**]

- Anisotropic Scintillator:
  - <u>**for heavy particles**</u> **the** light output and the pulse shape depends on the particle impinging direction with respect to the crystal axes
  - <u>**for γ/e**</u> the light output and the pulse shape are isotropic

First indication of anisotropy properties for a $ZnWO_4$ crystal scintillator:



- **$ZnWO_4$ anisotropic scintillator:** a very promising detector (NIMA544(2005)553, Eur. Phys. J. C 73 (2013) 2276): i) very good anisotropic features; ii) high level of radiopurity; iii) high light output, that is low energy threshold feasible; iv) high stability in the running conditions; v) sensitivity to small and large mass DM candidate particles; vi) detectors with ~ kg masses

Strategy and advantages to develop and study the $ZnWO_4$ anisotropic response to nuclear recoils for the ADAMO project

Eur. Phys. J. C 73 (2013) 2276

Density (g/cm^3)	*7.87*
Melting point (ºC)	*1200*
Structural type	*Wolframite*
Cleavage plane	*Marked (010)*
Hardness (Mohs)	*4–4.5*
Wavelength of emission maximum (nm)	*480*
Refractive index	*2.1–2.2*
Effective average decay time (µs)	*24*

Advantages of the $ZnWO_4$ crystal

- ✓ Very good anisotropic features
- ✓ High level of radio-purity
- ✓ High light output, that is low energy threshold feasible
- ✓ High stability in the running conditions
- ✓ Sensitivity to small and large mass DM candidate particles
- ✓ Detectors with ~ kg masses

The main ongoing R&Ds and studies:

- ➢ Increase the radio-purity level
- ➢ Increase the optical properties
- ➢ Increase the light yield to further decrease the energy threshold
- ➢ **Study the anisotropies property at energy of interest for DM particle nuclear recoils**

See next slides

- Optimization of purification procedure of the polders
- Optimization of crystallization protocols
- Development and optimization of re-crystallization procedures
- Study the light yield response vs the operation temperature

JINST15(2020)07,C07037; JINST15(2020)05,C05055; NIMA935(2019)89; NIMA833(2016)77; JPCS718(2016)4,042011; EPJC73(2013)2276; NIMA626-627(2011)3; JP38(2011)115107 NPA826(2009)256; PLB658(2008)193

Measurements of $ZnWO_4$ anisotropic response to nuclear recoils for the ADAMO project

- In summer 2018 a campaign of measurements using a dedicated $ZnWO_4$ crystal to study the anisotropic features of the detector for low energy nuclear recoils started

- Preliminary measurements with a collimated α source have been preformed

- After α calibrations a campaign of measurements at ENEA-Casaccia with a 14 MeV neutron beam has been carried out

$ZnWO_4$ crystal = 10.20 x 10.20 x 10.20 mm^3
(detector of reduced dimensions to investigate neutron single-scattering)

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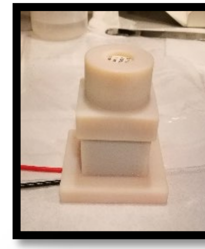
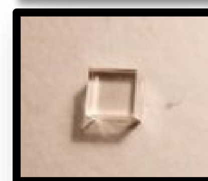
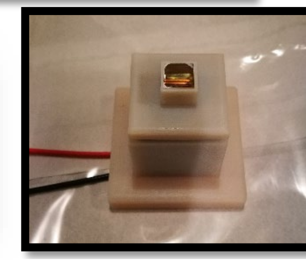
Studying the response of the $ZnWO_4$ with ^{241}Am α source

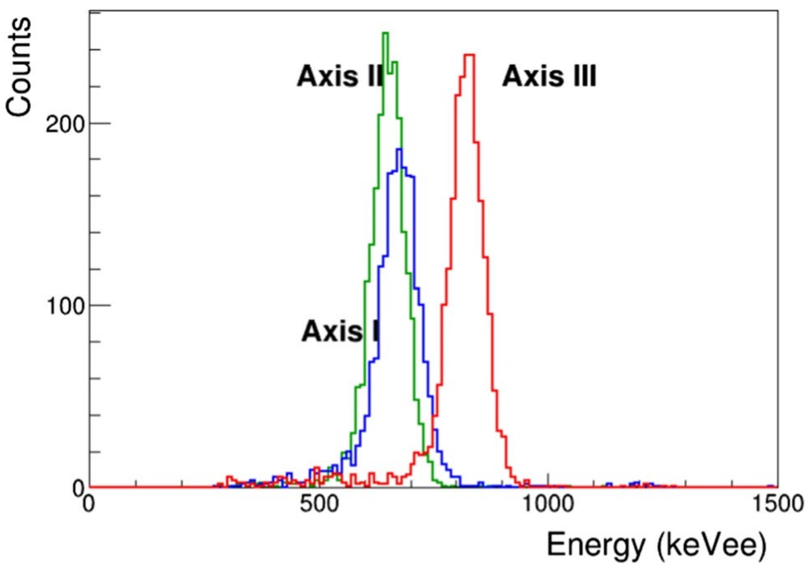
Calibration set-up:

- PMT Hamamatsu H11934-200 (T.T. $\approx$ 5 ns) + $ZnWO_4$
- LeCroy Oscilloscope 24Xs-A, 2.5 Gs/s, 200MHz band width
- Metallic Box
- Pulse profiles acquired in a time window of 100 μs









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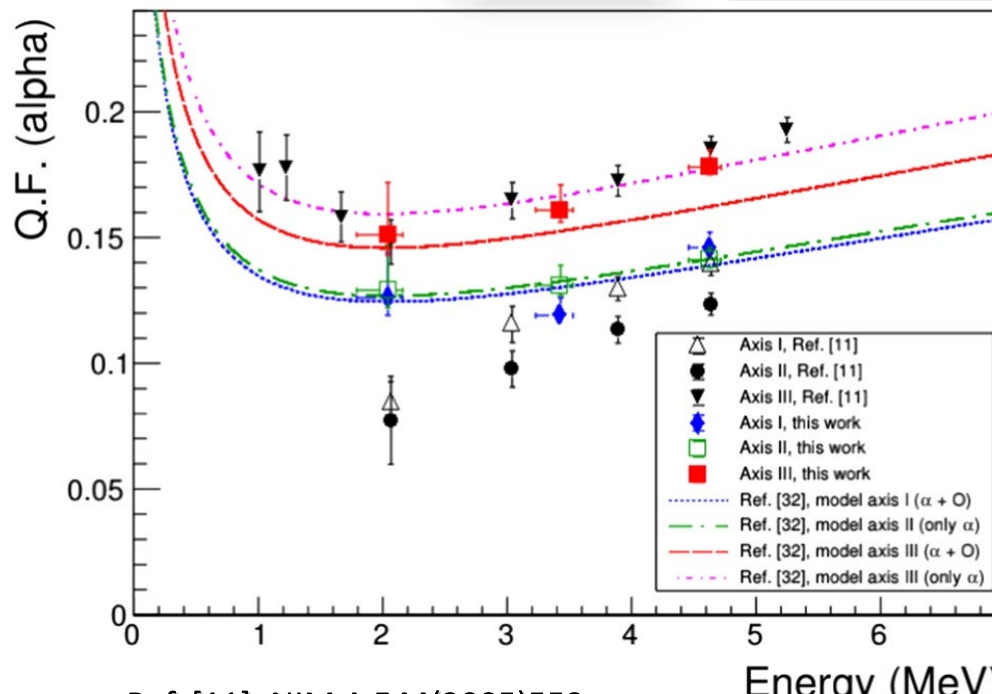
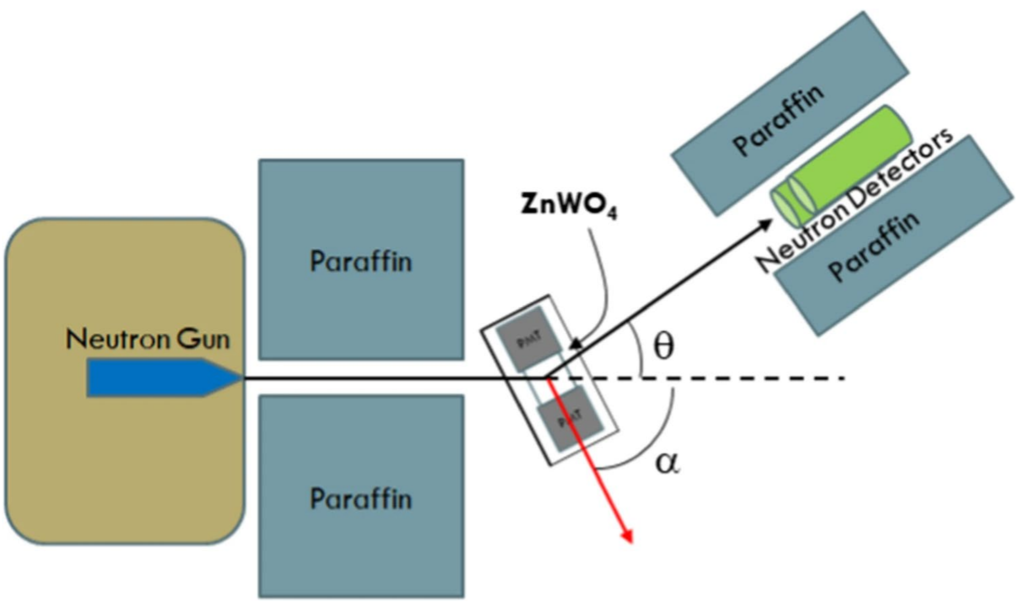


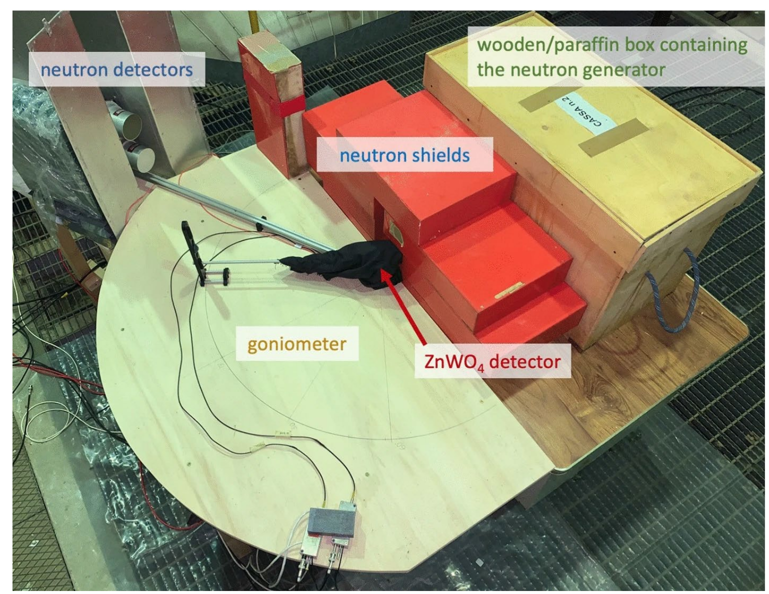
Ref. [11]: NIM A 544(2005)553

Studying the response of the $ZnWO_4$ with a neutron gun

- Set-up:
  - ✓ $ZnWO_4$ Crystal (10.20 x 10.20 x 10.20 mm^3)
  - ✓ PMT1 and 2: HAMA-H11934-200
  - ✓ 2 Neutron detectors (Scionix EJ-309)
  - ✓ Neutron Gun, Thermo Scientific MP320: 14 MeV neutrons

- Strategy: search for coincidence between a scattered neutron at a fixed angle and scintillation event in $ZnWO_4$ occurred in a well defined time window (ToF)
- Once fixed the θ angle, the recoil direction and energy are fixed
- Measurements performed at different θ angle





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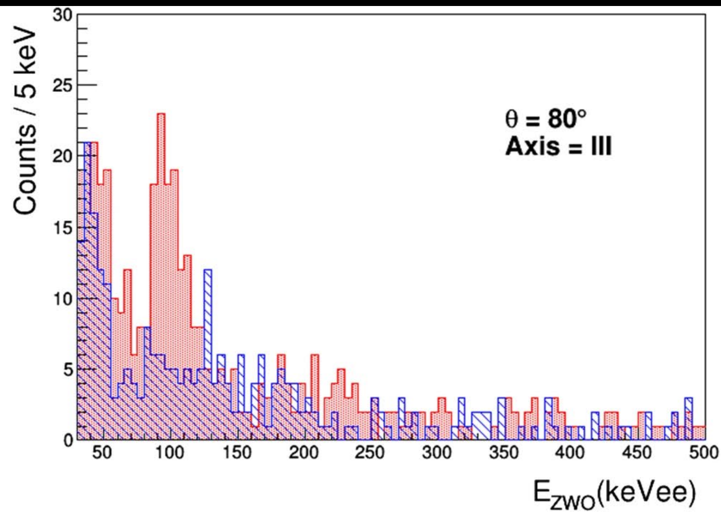
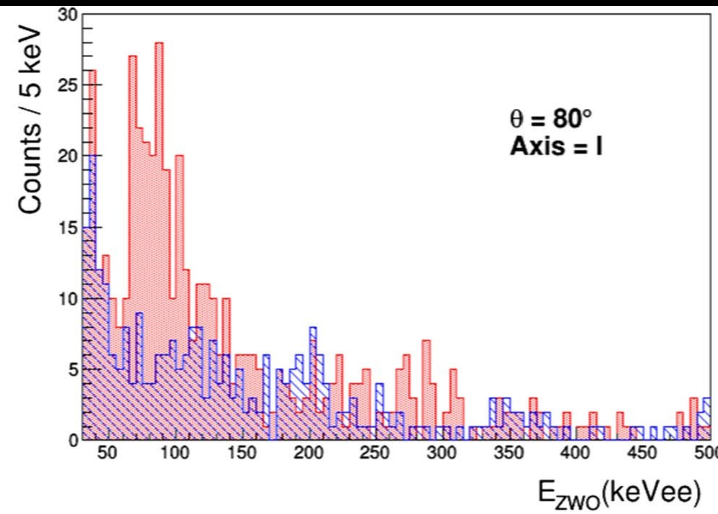
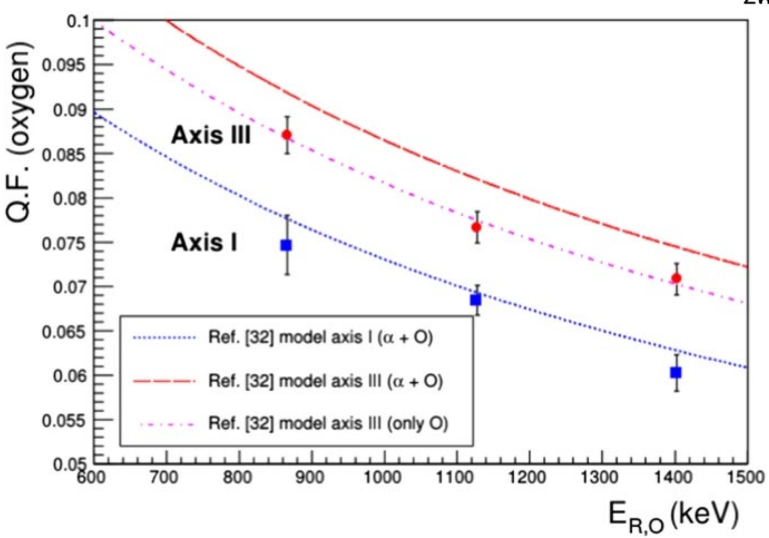
Studying the response of the $ZnWO_4$ with a neutron gun

Energy distributions in $ZnWO_4$ for coincidence events when neutrons are identified in EJ-309 and two ToF window are considered (θ=80°):

- ✓ -20 ns < ToF < 30 ns (**neutron induced recoils**)
- ✓ 60 ns < ToF < 110 ns (**random coincidences**)







The anisotropy is significantly evident also for oxygen nuclear recoils in the energy region down to some hundreds keV at 5.4 σ confidence level.

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Conclusions

- Anisotropic $ZnWO_4$ detectors are promising detectors to investigate the directionality for DM candidates inducing nuclear recoils

- First evidence of anisotropy in the response of $ZnWO_4$ crystal scintillator to low energy nuclear recoils reported

- The data presented here confirm the anisotropic response of the $ZnWO_4$ crystal scintillator to α particles in the MeV energy region. The anisotropy is significantly evident also for oxygen nuclear recoils in the energy region down to some hundreds keV at 5.4 σ confidence level.

- Such an experiment can obtain, with a completely different new approach, further evidence for the presence of some DM candidates in the galactic halo and provide complementary information on the nature and interaction type of the DM candidate