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Search for double charged particles as direct test for Dark Atom Constituents

VIA talk at XXth Bled Workshop

14-16 July 2017

Outlines

- Physical reasons of search for new particles with non-single charge (magnetic monoples, fractons, millicharges).
- Stability of double charged particles.
- Forms of Dark Atoms, their constituents, cosmological evolution and effects
- Accelerator search for charged components of composite dark matter

NONSINGLE CHARGES IN PHYSICS BEYOND THE STANDARD MODEL

Magnetic monopoles in BSM models

Dirac suggested an existence of magnetic monopole with magnetic charge

$$g = (2e)^{-1}$$

as condition of quantization of electric charge.

T'Hooft and Polyakov have shown, that in BSM models, where $U(1)_{e/m}$ symmetry is included to SU(3) or wider symmetry, magnetic monopole must appear in the result of spontaneous breaking of unifying symmetry as a topological defect of respective Higgs' field.

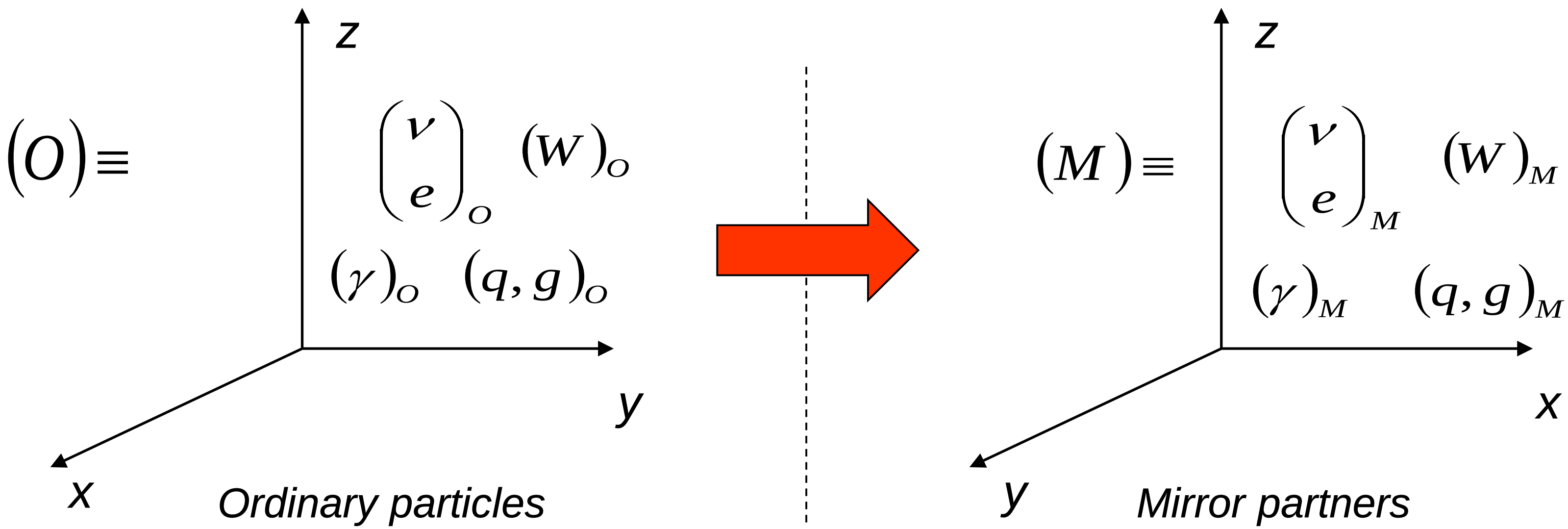
It is inevitable in GUT models, in which the mass of monopole is predicted to be

$$m_M \sim \Lambda_{\mathrm{GUT}} / \sqrt{\alpha} \qquad (\Lambda_{GUT} \sim 10^{15}\ \mathrm{GeV})$$

However mass of monopole can be much smaller, if the scale of compact group symmetry breaking is below GUT scale

Mirror world

Blinnikov,Khlopov(1980,1982,1984)



Assume that there is no common interaction between ordinary particles and their mirror partners, except for gravity. All the masses and coupling constants of mirror particles are strictly symmetric to the ordinary ones.The initial conditions are also assumed strictly symmetric.

Fractons

- Mixed states, having mirror and ordinary charges, have unusual properties.
- Mirror hadron, having ordinary electroweak charges, behaves as fractionally charged lepton.
- Ordinary quarks, having mirror electroweak charges, are neutral relative to ordinary electromagnetism and, bound with ordinary quarks, give rise to a colorless fractionally charged particles.
- While negatively charged « leptonic » fractons should be bound with nuclei and thus excape annihilation with their positively charged antiparticles, « hadronic » fractons possess mirror electromagnetic charges and owing to mirror Coulomb attraction diffuse to their antiparticles and annihilate in dense matter bodies.
- Recombination of hadronic fractons in matter makes their exitence compatible with stringent experimental upper limits on abundance of fractionally charged particles in terrestrial matter.

Millicharged particles

- If there are dark U(1) charged particles, due to dark-photon-ordinary photon mixing they can possess electromagnetic interaction with ordinary particles with ordinary charge suppressed by the mixing factor $\boldsymbol{\epsilon}$. Such particles behave like particles with millicharge $\boldsymbol{\epsilon} e$.

Experimental limits on nonsingle charge particles

- The most stringent limits to date were obtained by:
- CMS collaboration for the fractionally charged particles (200 and 480 GeV for charges e/3 and 2e/3, respectively).
- CMS collaboration for the multi-charged particles (685, 750, 790, 800, 780, 760, and 720 GeV for charges 2e, 3e, . . . , and 8e, respectively).
- ATLAS collaboration for the magnetic monopoles (up to 1340 GeV).

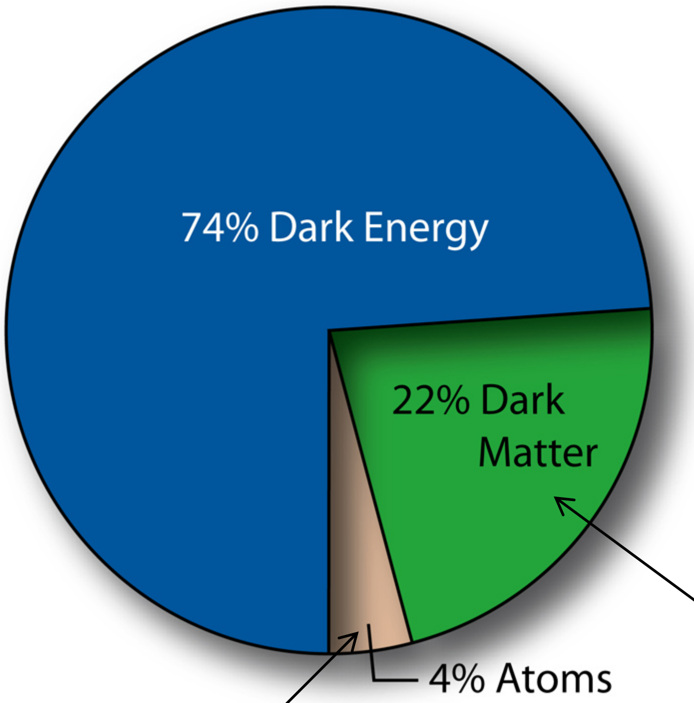
DOUBLE CHARGED PARTICLES

Stability of double charged particles

- If particle has double charge, it cannot decay to quarks, but only to pair of same sign leptons. It means that lepton number is not conserved in this decay and such decays imply lepton charge violation.
- Long lived particles may have important cosmological consequences.
- Indeed, double charged particles may play the role of constituents of composite dark matter – dark atoms.

THE PUZZLES
OF DARK MATTER SEARCH

Composition of the Universe



Baryonic matter consists of atoms

Can dark Matter consist of Dark atoms?

$$\Omega \equiv \frac{\rho}{\rho_{cr}}$$

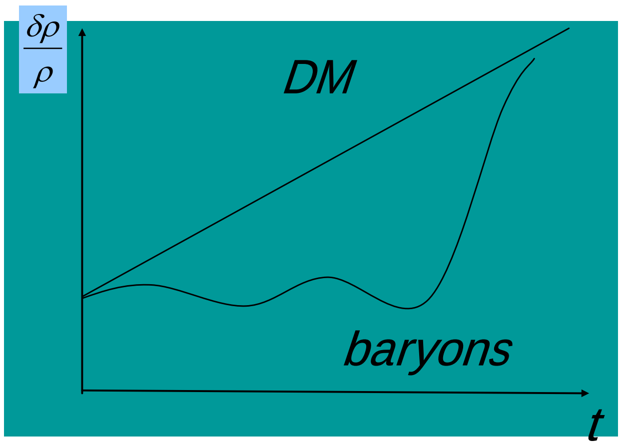
$$\Omega_b \approx 0.044 \qquad \Omega_{CMB} \approx 0.5 \cdot 10^{-4}$$

$$\Omega_{DM} \approx 0.20$$

$$\Omega_\Lambda \approx 0.7$$

$$\boxed{\Omega_{tot} \approx 1.0}$$

Cosmological Dark Matter



$$\frac{\delta\rho}{\rho} \Rightarrow \frac{\delta T}{T}$$

Cosmological Dark Matter explains:

- *virial paradox in galaxy clusters,*
- *rotation curves of galaxies*
- *dark halos of galaxies*
- *effects of macro-lensing*

But first of all it provides formation of galaxies from small density fluctuations, corresponding to the observed fluctuations of CMB

To fulfil these duties Dark Matter should interact sufficiently weakly with baryonic matter and radiation and it should be sufficiently stable on cosmological timescale

THE PUZZLES
OF DIRECT DARK MATTER
SEARCHES

Direct seaches for Dark Matter

Possibility of detecting relict massive neutrinos

V. F. Shvartsman, V. B. Braginskiĭ, S. S. Gershteĭn, Ya. B. Zel'dovich, and M. Yu. Khlopov

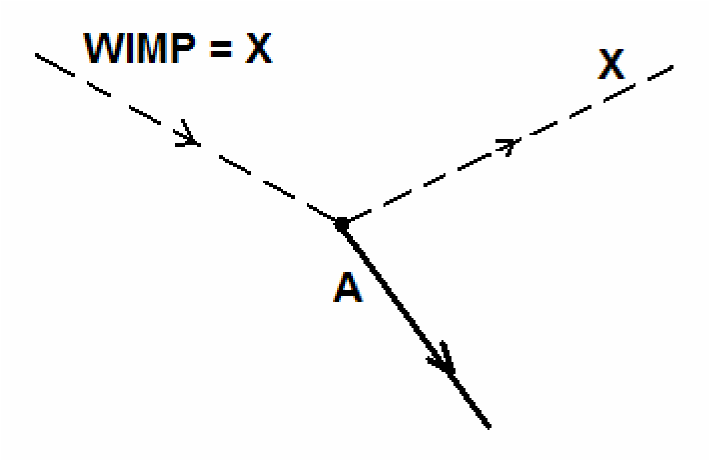
M. V. Keldysh Institute of Applied Mathematics, Academy of Sciences of the USSR

(Submitted 18 August 1982)
Pis'ma Zh. Eksp. Teor. Fiz. **36**, No. 6, 224–226 (20 September 1982)

The coherent intensification of the interaction of relict massive neutrinos with grains of matter with a size on the order of the neutrino wavelength suggests that it might be possible to detect a galactic neutrino sea by virtue of the mechanical pressure which it exerts in the direction opposite that in which the solar system is moving in the galaxy.

WIMP-nucleus interaction

CDM can consist of Weakly Interacting Massive Particles (WIMPs).
Such particles can be searched by effects of WIMP-nucleus interactions.



$$\Delta T = 0 \div \Delta T_{\max} = \frac{q_{\max}^2}{2m_A} = \frac{2\mu^2 v^2}{m_A} \xrightarrow[m_X >> m_A]{} 2m_A v^2$$

$$v \sim 300\frac{\text{km}}{\text{s}}, \qquad \Delta T \sim 10\text{keV}$$

$\Delta T_{\max} < E_A^* \Rightarrow$ elastic scattering

$q_{(\max)} R_A > 1 \Rightarrow$ non-pointlike nucleus

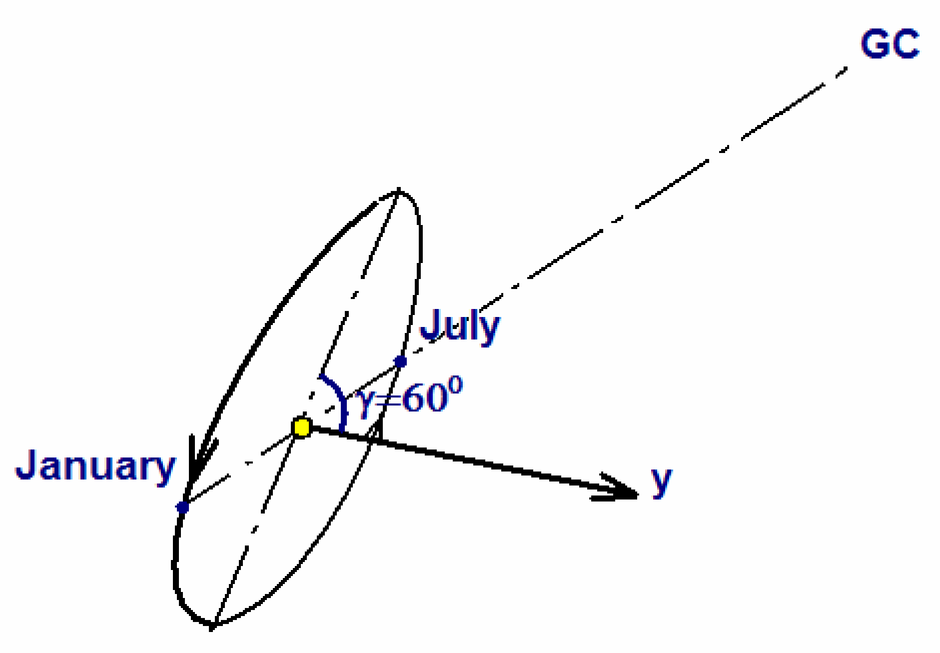
$$Interaction\ amplitude \equiv A_{AX} = A_{AX}^{\text{point}} \cdot F_A(q^2)$$

Annual modulation of WIMP effects

Minimization of background

- Installation deeply underground
- Radioactively pure materials
- Annual modulation

DM does not participate in rotation around GC.



$$v_{Earth\ y} = v_{Sun\ y} + v_{orb} \cdot \cos\gamma \cdot \cos\omega(t - t_0)$$

$$v_{Sun\ y} = 220 + 16.5 \cdot \cos 25° \cdot \sin 53° \text{ (km/s)}$$

$$t_0 = 2 \text{ June}$$

$$Amplitude <\sim \frac{v_{orb} \cdot \cos\gamma}{v_{Sun\ y}} \sim \frac{15}{232} \sim 7\%$$

Model Independent Annual Modulation Result

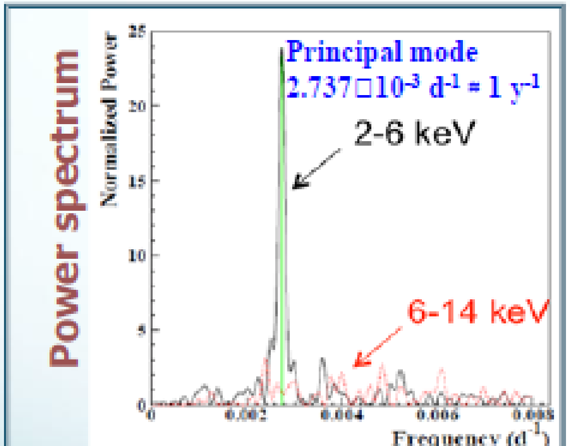
DAMA/NaI + DAMA/LIBRA-phase1 Total exposure: 487526 kg×day = **1.33 ton×yr**

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

The measured modulation amplitudes (A), period (T) and phase (t_0) from the single-hit residual rate vs time

	A(cpd/kg/keV)	T=2π/ω (yr)	t_0 (day)	C.L.
DAMA/NaI+DAMA/LIBRA-phase1				
(2-4) keV	0.0190 ±0.0020	0.996 ±0.0002	134 ± 6	9.5σ
(2-5) keV	0.0140 ±0.0015	0.996 ±0.0002	140 ± 6	9.3σ
(2-6) keV	0.0112 ±0.0012	0.998 ±0.0002	144 ± 7	9.3σ

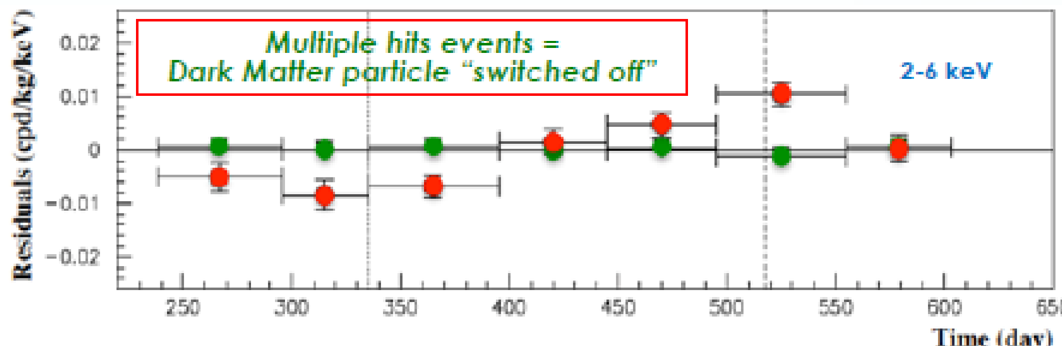
$A\cos[\omega(t-t_0)]$



No systematics or side reaction able to account for the measured modulation amplitude and to satisfy all the peculiarities of the signature

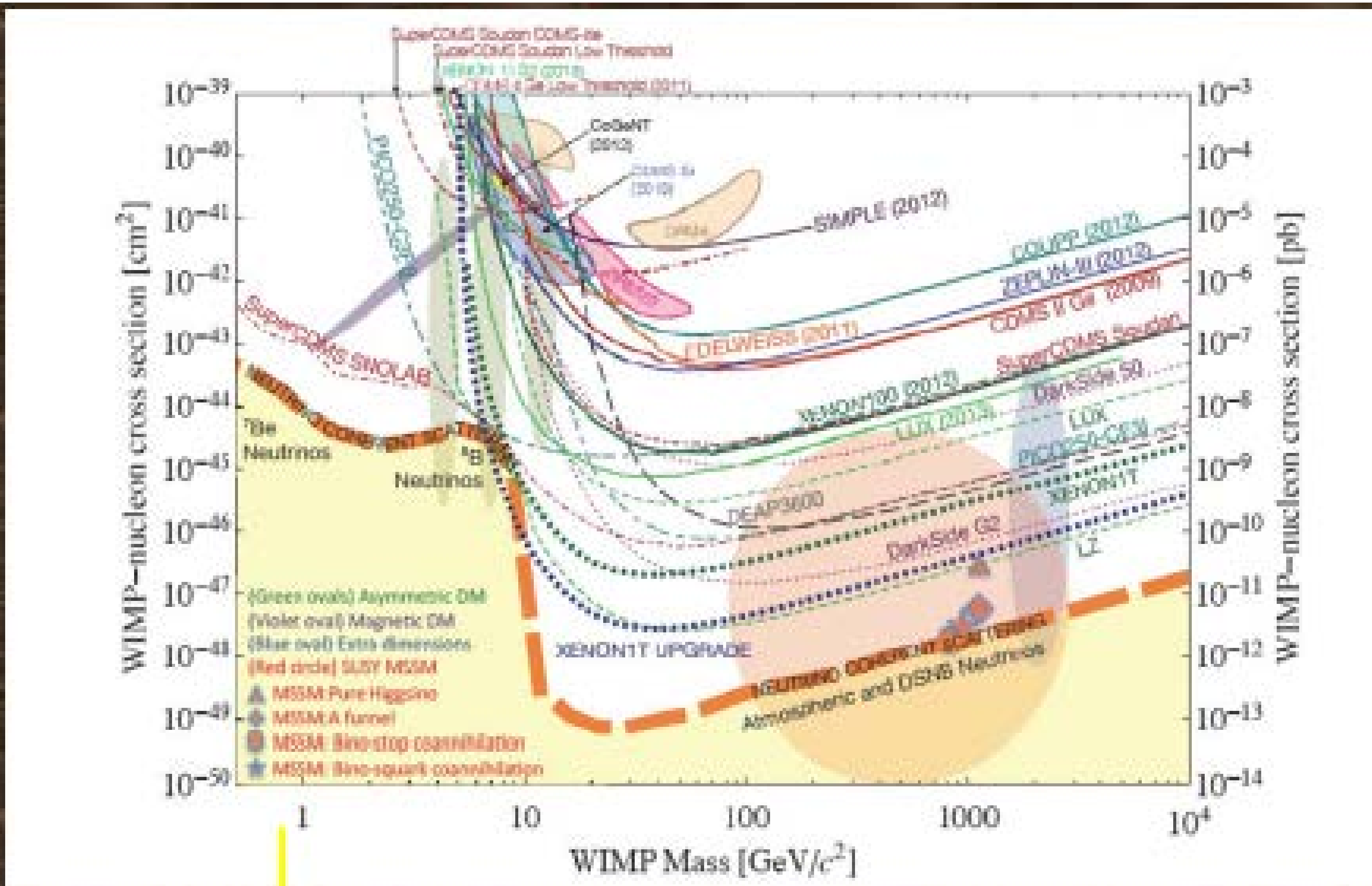
Comparison between single hit residual rate (red points) and multiple hit residual rate (green points); Clear modulation in the single hit events; No modulation in the residual rate of the multiple hit events

A=-(0.0005±0.0004) cpd/kg/keV



This result offers an additional strong support for the presence of DM particles in the galactic halo further excluding any side effect either from hardware or from software procedures or from background

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.



This is just a largely arbitrary, partial, incorrect exercise

THE PUZZLES
OF INDIRECT DARK MATTER
SEARCHES

Indirect searches for Dark Matter

Astrophysical bounds on the mass of heavy stable neutral leptons

Ya. B. Zel'dovich, A. A. Klypin, M. Yu. Khlopov, and V. M. Chechetkin

Institute of Applied Mathematics, USSR Academy of Sciences
(Submitted 29 November 1979)
Yad. Fiz. **31**, 1286–1294 (May 1980)

Analytical and numerical calculations show that heavy neutral stable leptons are carried along by the collapsing matter during the formation of galaxies and possibly stars as well. The condensation in galaxies and stars results in appreciable annihilation of leptons and antileptons. Modern observations of cosmic-ray and γ-ray fluxes establish a limit $m_\nu \gtrsim 100$ GeV for the mass of neutral leptons, since annihilation of neutral leptons produces γ rays and cosmic rays. The obtained bound, in conjunction with ones established earlier, precludes the existence of stable neutral leptons (neutrinos) with $m_\nu > 30$ eV.

Condensation of Dark Matter in Galaxy

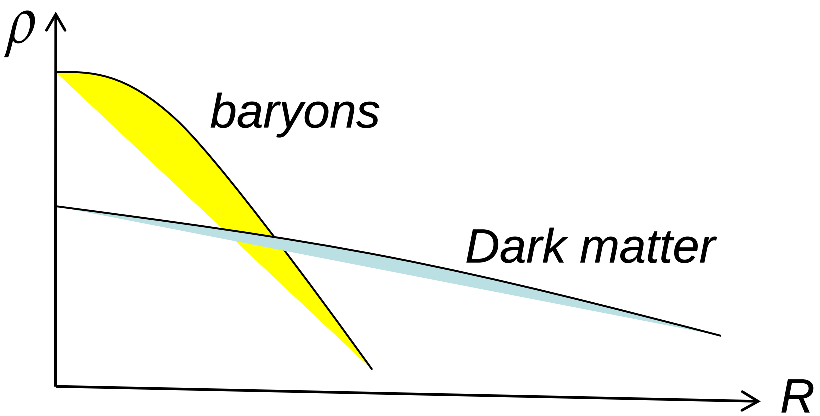
$$\ddot{R} + \omega^2 R = 0$$

$$\omega^2 = 4\pi G(\rho_\nu + \rho_b)$$

$$I = \frac{E(t)}{\omega(t)} = \frac{\omega^2 R^2}{2\omega} = const$$

$$\rho_\nu(t) \propto R^{-3} \propto \omega^{3/2} \propto [\rho_b(t)]^{3/4}$$

$$\rho_\nu(t) \propto [\rho_b(t)]^{3/4}$$



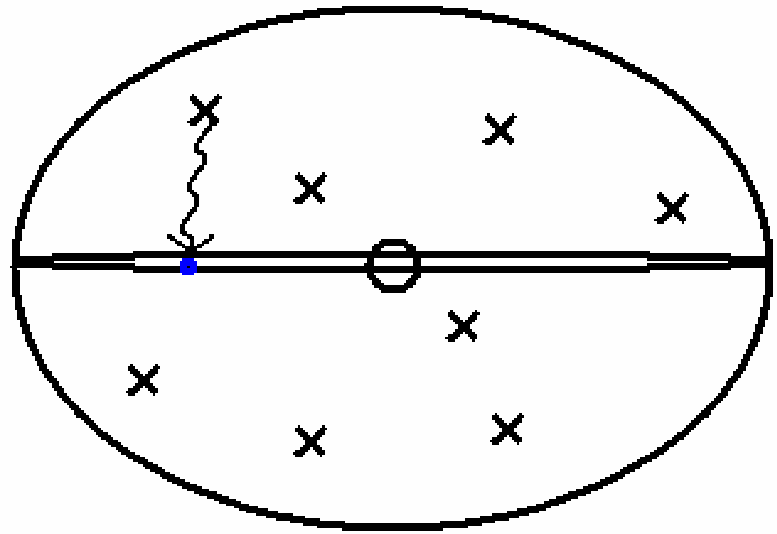
- Motion of collisionless gas in nonstationary field of baryonic matter, contracting owing to dissipation processes, provides effective dissipation and contraction of this gas.
- In result collisionless Dark Matter condences in Galaxy, but it is distributed more steeply, than baryonic matter.
- It qualitatively explains the difference in distribution of baryons and dark matter.
- Due to condensation effects of annihilation in Galaxy can be significant even for subdominant DM components (e.g.4th neutrino).

Annihilation and decays of DM as a source of CR.

Stable DM particles can annihilate

$$\dot{n}_{sources} = n_X n_{\tilde{X}} \langle \sigma_{ann} v \rangle$$

$$X\tilde{X} \rightarrow e^+ e^- + \ldots$$



Metastable neutral particles decay with equal amount of positrons and electrons

$$X \rightarrow e^+ e^- + \ldots$$

At the level of elementary process metastable double charged particles can decay to same sign leptons only

$$X^{++} \rightarrow l^+ l^+$$

The excess of high energy positrons detected in PAMELA, FERMI/LAT and AMS02 experiments may be considered as an evidence for indirect effect of dark matter, first predicted by Zeldovich et al (1980).

Cosmic positron excess from DM?

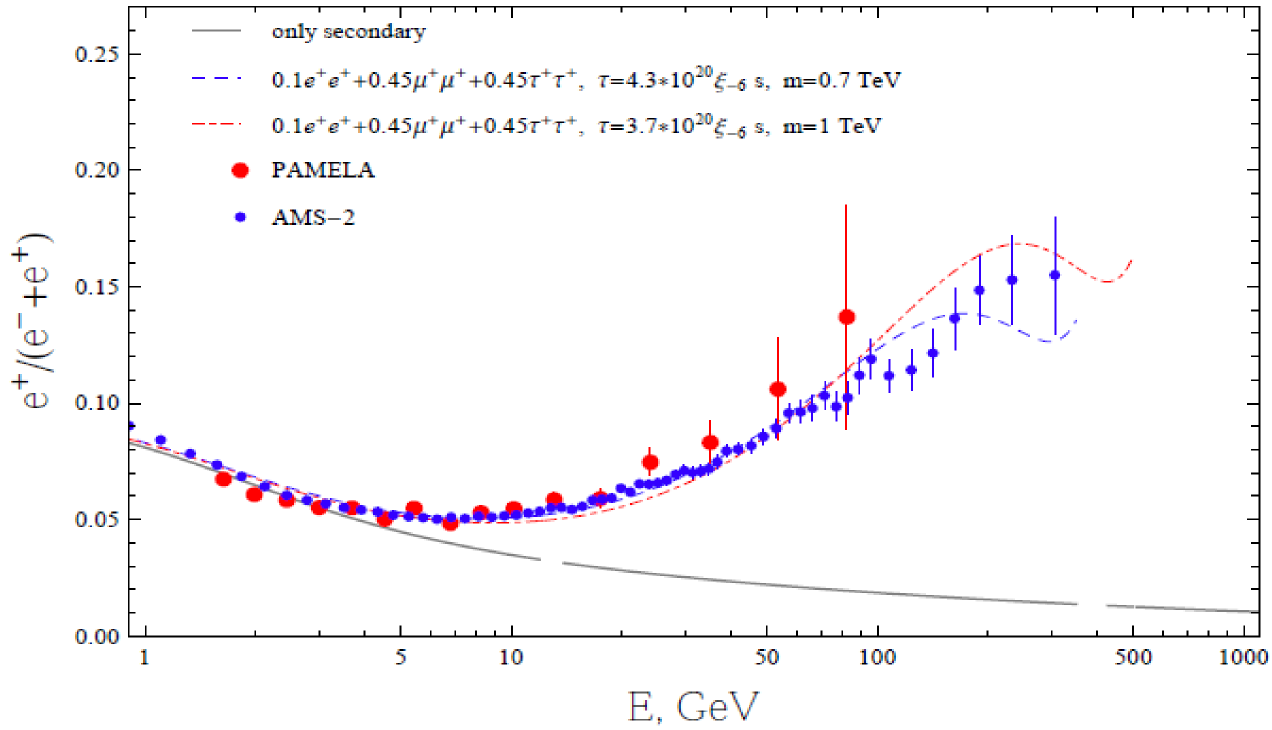
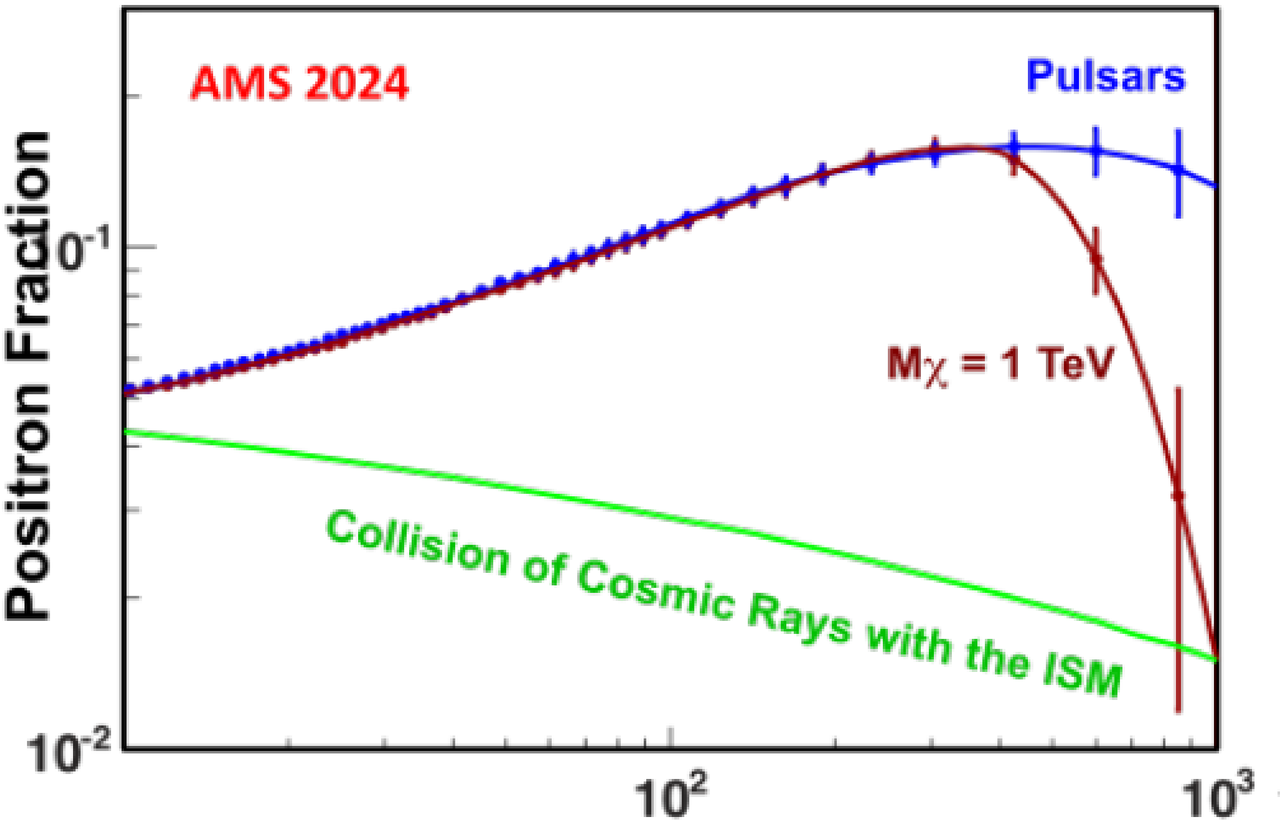


Figure 3: Positron excess due to $UU \to e^+e^+, \mu^+\mu^+, \tau^+\tau^+$ decays compared to PAMELA and AMS-02 data.

Probably such indirect effect is detected in the cosmic positron fluxes.

[figure from K.M.Belotsky et al. arXiv:1403.1212]

AMS02 in the next decade



Presented in CERN on 08.12.2016 by Prof. S.Ting

INTEGRAL excess of positron annihilation line

- In the galactic bulge the excess of positron annihilation line is observed by INTEGRAL.
- This effect may be due to extra positrons originated from dark matter.

DARK MATTER FROM CHARGED PARTICLES?

Baryonic Matter – atoms of stable quarks and charged lepton (electron)

- Ordinary matter consists of atoms
- Atoms consist of nuclei and electrons.
- Electrons are lightest charged particles – their stability is protected by the conservation of electric charge.
- Nuclei consist of nucleons, whose stability reflects baryon charge conservation.

In ordinary matter stable elementary particles are electrically charged, but bound in neutral atoms.

Dark Matter from Charged Particles?

By definition Dark Matter is non-luminous, while charged particles are the source of electromagnetic radiation. Therefore, neutral weakly interacting elementary particles are usually considered as Dark Matter candidates. If such neutral particles with mass m are stable, they freeze out in early Universe and form structure of inhomogeneities with the minimal characterstic scale

$$M = m_{Pl}\left(\frac{m_{Pl}}{m}\right)^2$$

- However, if charged particles are heavy, stable and bound within neutral « atomic » states they can play the role of composite Dark matter.
- Physical models, underlying such scenarios, their problems and nontrivial solutions as well as the possibilities for their test are the subject of the present talk.

« No go theorem » for -1 charge components

- *If composite dark matter particles are « atoms », binding positive P and negative E charges, all the free primordial negative charges E bind with He-4, as soon as helium is created in SBBN.*
- *Particles E with electric charge -1 form +1 ion [E He].*
- *This ion is a form of anomalous hydrogen.*
- Its Coulomb barrier prevents effective binding of positively charged particles P with E. These positively charged particles, bound with electrons, become atoms of anomalous istotopes
- *Positively charged ion is not formed, if negatively charged particles E have electric charge -2.*

Nuclear-interacting composite dark matter: O-helium « atoms »

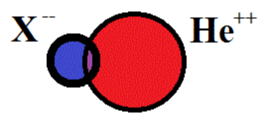
If we have a stable double charged particle X^{--} *in excess over its partner* X^{++} *it may create Helium like neutral atom (O-helium) at temperature* $T < I_o$

Where:

$$I_o = Z_{He}^2 Z_\Delta^2 \alpha^2 m_{He} = 1.6 MeV$$

^4He is formed at T ~100 keV (t~100 s)
This means that it would rapidly create a neutral atom, in which all X^{--} are bound

$$X^{--} + {}^4He => (X\ He) + \gamma$$



The Bohr orbit of O-helium « atom » is of the order of radius of helium nucleus.

$$R_o = 1/\left(Z Z_{He} \alpha m_{He}\right) = 2 \cdot 10^{-13} cm$$

References

1. M.Yu. Khlopov, *JETP Lett.* 83 (2006) 1;
2. D. Fargion, M.Khlopov, C.Stephan, *Class. Quantum Grav.* 23 (2006) 7305;
2. M. Y. Khlopov and C. Kouvaris, *Phys. Rev.* D 77 (2008) 065002]

Constituents of composite dark matter

Few possible candidates for -2 charges:

Stable doubly charged "leptons" with mass >100 GeV (~1 TeV range):

- *AC « leptons » from almost commutative geometry*

D. Fargion, M.Khlopov, C.Stephan, Class. Quantum Grav. 23 (206) 7305

- *Technibaryons and technileptons from Walking Technicolor (WTC)*

M. Y. Khlopov and C. Kouvaris, Phys. Rev. D 77 (2008) 065002; M. Y. Khlopov and C. Kouvaris, Phys. Rev. D 78 (2008) 065040

Hadron-like bound states of:

- *Stable U-quark of 4-th family in Heterotic string phenomenology*

M.Yu. Khlopov, *JETP Lett.* 83 (2006) 1

- *Stable U-quarks of 5th family in the approach, unifying spins and charges*

N.S. Mankoc Borstnik, Mod. Phys. Lett. A 10 (1995) 587

M.Yu.Khlopov, A.G.Mayorov, E.Yu.Soldatov (2010), arXiv:1003.1144

O-HELIUM DARK MATTER

O-helium dark matter

$$T < T_{od} = 1keV$$

$$n_b \langle \sigma v \rangle \left(m_p / m_o \right) t < 1$$

$$T_{RM} = 1eV$$

$$M_{od} = \frac{T_{RM}}{T_{od}} m_{Pl} \left(\frac{m_{Pl}}{T_{od}} \right)^2 = 10^9 M_{Sun}$$

- Energy and momentum transfer from baryons to O-helium is not effective and O-helium gas decouples from plasma and radiation
- O-helium dark matter starts to dominate
- On scales, smaller than this scale composite nature of O-helium results in suppression of density fluctuations, making O-helium gas Warmer than Cold Dark Matter

O-helium in Earth

- Elastic scattering dominates in the (OHe)-nucleus interaction. After they fall down terrestrial surface the in-falling OHe particles are effectively slowed down due to elastic collisions with the matter. Then they drift, sinking down towards the center of the Earth with velocity

$$V = \frac{g}{n\sigma v} \approx 80 S_3 A_{med}^{1/2} \text{ cm/s}.$$

Here $A_{med} \sim 30$ is the average atomic weight in terrestrial surface matter, $n = 2.4 \cdot 10^{24}/A_{med}$ is the number of terrestrial atomic nuclei, σv is the rate of nuclear collisions and $g = 980 \text{ cm/s}^2$.

O-helium experimental search?

- In underground detectors, (OHe) “atoms” are slowed down to thermal energies far below the threshold for direct dark matter detection. However, (OHe) nuclear reactions can result in observable effects.
- O-helium gives rise to less than 0.1 of expected background events in XQC experiment, thus avoiding severe constraints on Strongly Interacting Massive Particles (SIMPs), obtained from the results of this experiment.

It implies development of specific strategy for direct experimental search for O-helium.

O-HELIUM DARK MATTER IN UNDERGROUND DETECTORS

O-helium concentration in Earth

The O-helium abundance the Earth is determined by the equilibrium between the in-falling and down-drifting fluxes.

The in-falling O-helium flux from dark matter halo is

$$F = \frac{n_0}{8\pi} \cdot |\overline{V_h} + \overline{V_E}|,$$

where ***V****$_h$* is velocity of Solar System relative to DM halo (220 km/s), ***V****$_E$* is velocity of orbital motion of Earth (29.5 km/s) and

$n_0 = 3 \cdot 10^{-4} S_3^{-1}\,\mathrm{cm}^{-3}$ is the local density of O-helium dark matter.

At a depth *L* below the Earth's surface, the drift timescale is ~*L/V.* It means that the change of the incoming flux, caused by the motion of the Earth along its orbit, should lead at the depth L ~ 10^5 cm to the corresponding change in the equilibrium underground concentration of OHe on the timescale

$$t_{dr} \approx 2.5 \cdot 10^2 S_3^{-1}\,\mathrm{s}$$

Annual modulation of O-helium concentration in Earth

The equilibrium concentration, which is established in the matter of underground detectors, is given by

$$n_{oE} = \frac{2\pi \cdot F}{V} = n_{oE}^{(1)} + n_{oE}^{(2)} \cdot sin(\omega(t - t_0)),$$

where $\omega = 2\pi/T$, T=1yr and t_o is the phase. The averaged concentration is given by

$$n_{oE}^{(1)} = \frac{n_o}{320 S_3 A_{med}^{1/2}} V_h$$

and the annual modulation of OHe concentration is characterized by

$$n_{oE}^{(2)} = \frac{n_o}{640 S_3 A_{med}^{1/2}} V_E$$

The rate of nuclear reactions of OHe with nuclei is proportional to the local concentration and the energy release in these reactions leads to ionization signal containing both constant part and annual modulation.

OHe solution for puzzles of direct DM search

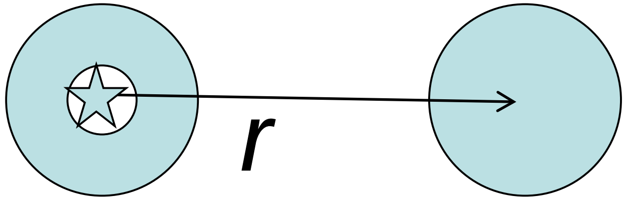
- OHe equilibrium concentration in the matter of DAMA detector is maintained for less than an hour
- The process

$$OHe + (A,Z) \Rightarrow \left[OHe\left(A,Z\right)\right] + \gamma$$

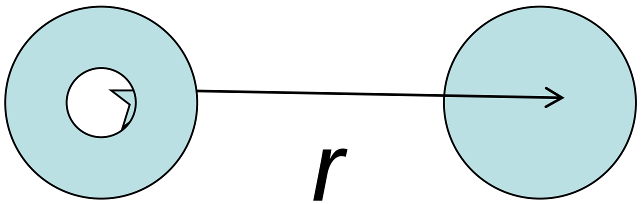
is possible, in which only a few keV energy is released. Other inelastic processes are suppressed

- Annual modulations in inelastic processes, induced by OHe in matter. No signal of WIMP-like recoil
- Signal in DAMA detector is not accompanied by processes with large energy release. This signal corresponds to a formation of anomalous isotopes with binding energy of few keV

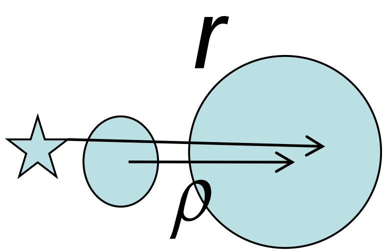
Potential of OHe-nucleus interaction



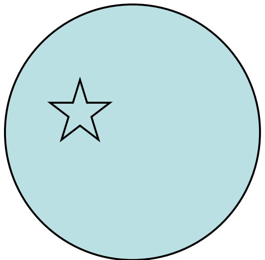
$$U_{Xnuc} = -2Z\alpha\left(\frac{1}{r} + \frac{1}{r_o}\right)\exp\left(-2r/r_o\right)$$



$$U_{Stark} = -\frac{2Z\alpha}{r^4}\frac{9}{2}r_o^3$$

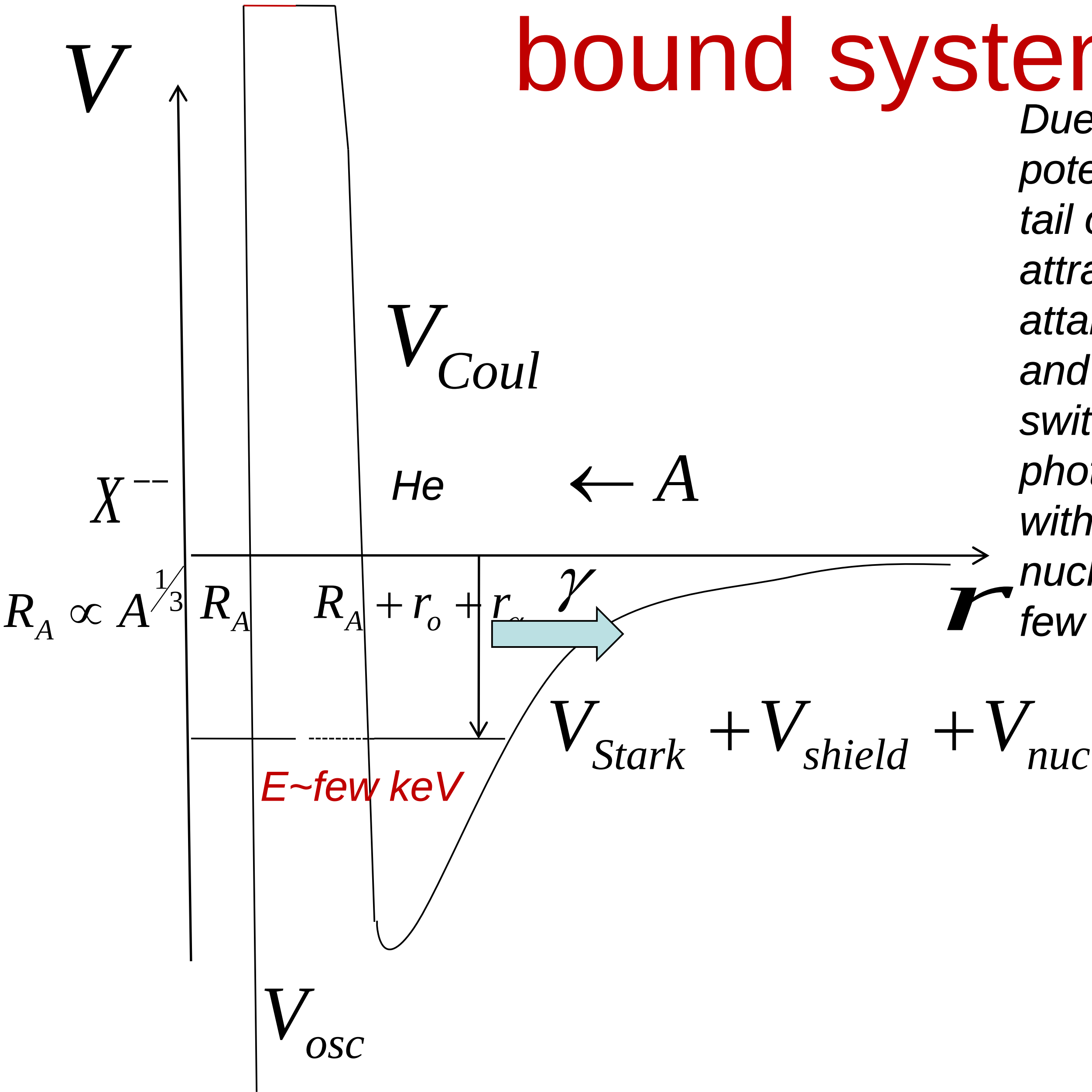


$$U_{Coul} = +\frac{2\alpha Z}{\rho} - \frac{2\alpha Z}{r}$$



$$U_{osc} = -\left[\frac{(Z+2)\alpha}{R}\left(1 - \left(\frac{r}{R}\right)^2\right)\right]$$

Formation of OHe-nucleus bound system



Due to shielded Coulomb potential of X, Stark effect and tail of nuclear Yukawa force OHe attracts the nucleus. Nuclear attarction causes OHe excitation and Coulomb repulsion is switched on. If the system emits a photon, OHe forms a bound state with nucleus but ***beyond*** *the nucleus with binding energy of few keV.*

Few keV Level in OHe-nucleus system

- The problem is reduced to a quantum mechanical problem of energy level of OHe-nucleus bound state in the potential well, formed by shielded Coulomb, Stark effect and Yukawa tail attraction and dipole-like Coulomb barrier for the nucleus in vicinity of OHe. The internal well is determined by oscillatory potential of X in compound (Z+2) nucleus, in which He is aggregated.
- The numerical solution for this problem is simplified for rectangular wells and walls, giving a few keV level for Na.

Rate of OHe-nucleus radiative capture

As soon as the energy of level is found one can use the analogy with radiative capture of neutron by proton with the account for:

- Absence of M1 transition for OHe-nucleus system (which is dominant for n+p reaction)
- Suppression of E1 transition by factor $f \sim 10^{-3}$, corresponding to isospin symmetry breaking

(in the case of OHe only isoscalar transition is possible, while E1 goes due to isovector transition only)

Reproduction of DAMA/NaI and DAMA/LIBRA events

The rate of OHe radiative capture by nucleus with charge Z and atomic number A to the energy level E in the medium with temperature T is given by

$$\sigma v = \frac{f \pi \alpha}{m_p^2} \frac{3}{\sqrt{2}} \left(\frac{Z}{A}\right)^2 \frac{T}{\sqrt{A m_p E}}.$$

Formation of OHe-nucleus bound system leads to energy release of its binding energy, detected as ionization signal. In the context of our approach the existence of annual modulations of this signal in the range 2-6 keV and absence of such effect at energies above 6 keV means that binding energy of Na-Ohe system in DAMA experiment should not exceed 6 keV, being in the range 2-4 keV.

Annual modulation of signals in DAMA/NaI and DAMA/LIBRA events

The amplitude of annual modulation of ionization signal (measured in counts per day per kg, cpd/kg) is given by

$$\zeta = \frac{3\pi\alpha \cdot n_o N_A V_E t Q}{640\sqrt{2} A_{med}^{1/2} (A_I + A_{Na})} \frac{f}{S_3 m_p^2} (\frac{Z_i}{A_i})^2 \frac{T}{\sqrt{A_i m_p E_i}} = 4.3 \cdot 10^{10} \frac{f}{S_3^2} (\frac{Z_i}{A_i})^2 \frac{T}{\sqrt{A_i m_p E_i}}.$$

This value should be compared with the integrated over energy bins signals in DAMA/NaI and DAMA/LIBRA experiments and the results of these experiments can be reproduced for

$$E_{Na} = 3keV$$

OPEN QUESTIONS OF THE OHE SCENARIO

Earth shadow effect

- OHe is nuclear interacting and thus should cause the Earth shadow effect.
- The studies, whether we can avoid recent DAMA constraints are under way.

THE PROBLEM OF POTENTIAL BARRIER

The crucial role of potential barrier in OHe-nucleus interaction

- Due to this barrier elastic OHe-nucleus scattering strongly dominates.
- If such barrier doesn't exist, overproduction of anomalous isotopes is inevitable.
- Its existence should be proved by proper quantum mechanical treatment

J.-R. Cudell, M.Yu;Khlopov and Q.Wallemacq

Some Potential Problems of OHe Composite Dark Matter,

Bled Workshops in Physics (2014) V.15, PP.66-74; e-Print: arXiv: 1412.6030.

SENSITIVITY INDIRECT EFFECTS OF COMPOSITE DARK MATTER TO THE MASS OF THEIR DOUBLE CHARGED CONSTITUENTS

Excessive positrons in Integral

Taking into account that in the galactic bulge with radius ~ 1 kpc the number density of O-helium can reach the value

$$n_o \approx 3 \cdot 10^{-3}/S_3\,\mathrm{cm}^{-3}$$

one can estimate the collision rate of O-helium in this central region:

$$dN/dt = n_o^2 \sigma v_h 4\pi r_b^3/3 \approx 3 \cdot 10^{42} S_3^{-2}\,s^{-1}$$

At the velocity of particules in halo, energy transfer in such collisions is E ~ 1MeV. These collisions can lead to excitation of O-helium. If 2S level is excited, pair production dominates over two-photon channel in the de-excitation by E0 transition and positron production with the rate

$$3 \cdot 10^{42} S_3^{-2}\,\mathrm{s}^{-1}$$

is not accompanied by strong gamma signal. This rate of positron production is sufficient to explain the excess of positron production in bulge, measured by Integral.

Excessive positrons in Integral from dark atoms– high sensitivity to DM distribution

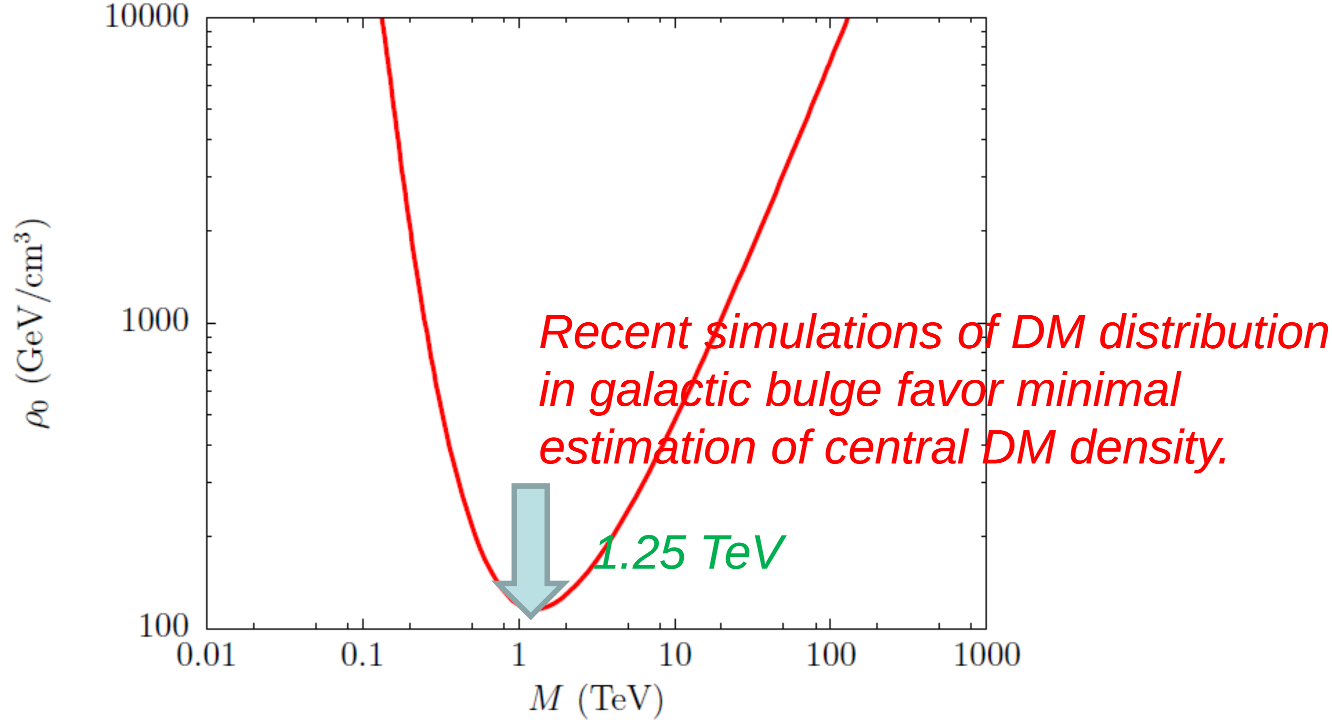


Figure 1: Values of the central dark matter density ρ_0 (GeV/cm^3) and of the OHe mas M (TeV) reproducing the excess of e^+e^- pairs production in the galactic bulge. Belo the red curve, the predicted rate is too low.

J.-R. Cudell, M.Yu.Khlopov and Q.Wallemacq
Dark atoms and the positron-annihilation-line excess in the galactic bulge.
Advances in High Energy Physics, vol. 2014, Article ID 869425, : arXiv: 1401.5228

Composite dark matter explanation for low energy positron excess

- In spite of large uncertainty of DM distribution in galactic bulge, where baryonic matter dominates and DM dynamical effects are suppressed, realistic simulations favor lower value of DM central density around $\rho_0 \simeq 115$ GeV/cm^3. Then observed excess of positron annihilation line can be reproduced in OHe model only at the mass of its heavy double charged constituent:
- $M \simeq 1.25$ TeV

A solution for cosmic positron excess?

- In WTC: if both technibaryons UU and technileptons ζ are present, CDMS, LUX results constrain WIMP-like (UUζ) component to contribute no more than 0,0001% of total DM density.
- Decays of positively charged UU->$l^+ l^+$ with a lifetime of about $10^{21} s$ and mass 700-1000 GeV can explain the excess of cosmic positrons, observed by PAMELA and AMS02

Cosmic positron excess from double charged constituents of dark atoms

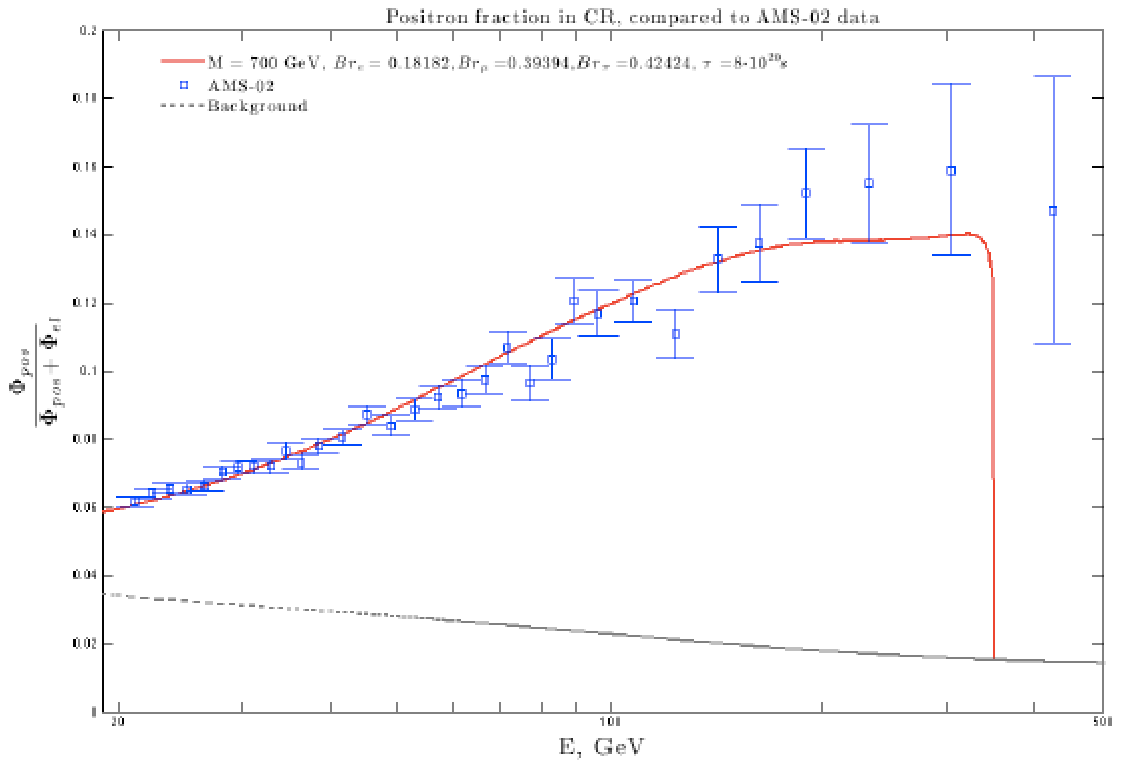


Figure 3: Positron fraction in the cosmic rays from decays of dark matter particles (red curve), corresponding to the best-fit values of model parameters ($M = 700\,\mathrm{GeV}, \tau = 8 \cdot 10^{20}\,\mathrm{s}, Br_{ee} = 0.182, Br_{\mu\mu} = 0.394, Br_{\tau\tau} = 0.424$), and fraction of secondary positrons (gray line), compared to the latest AMS-02 data [34] (blue dots).

Probably such indirect effect is detected in the cosmic positron fluxes.

[figure from K.M.Belotsky et al. Int.J.Mod.Phys. D24 (2015) 1545004 arXiv:1508.02881]

Diffuse Gamma ray background

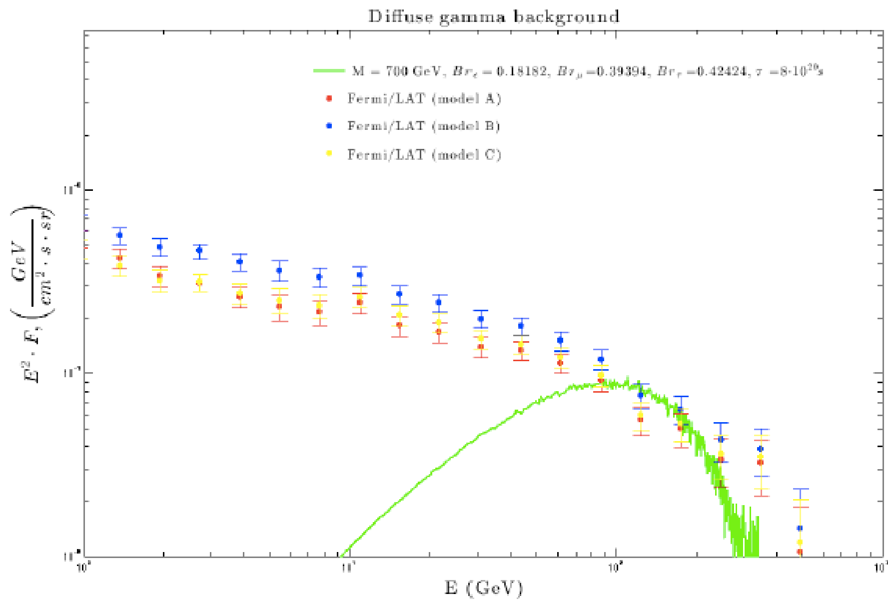


Figure 4: Gamma-ray flux multiplied by E^2 from decays of dark matter particles in the Galaxy and beyond (green curve), corresponding to the best-fit values of model parameters ($M = 700\,\mathrm{GeV}, \tau = 8 \cdot 10^{20}\,\mathrm{s}, Br_{ee} = 0.182, Br_{\mu\mu} = 0.394, Br_{\tau\tau} = 0.424$), compared to the latest FERMI/LAT data on isotropic diffuse gamma-ray background [42] ($|b| > 20°, 0° \leq l < 360°$ with point sources removed and without diffuse emission attributed to the interactions of Galactic cosmic rays with gas and radiation fields (foreground); here three different foreground models A (red dots), B (blue dots) and C (yellow dots) are shown). In our analysis we have used model B.

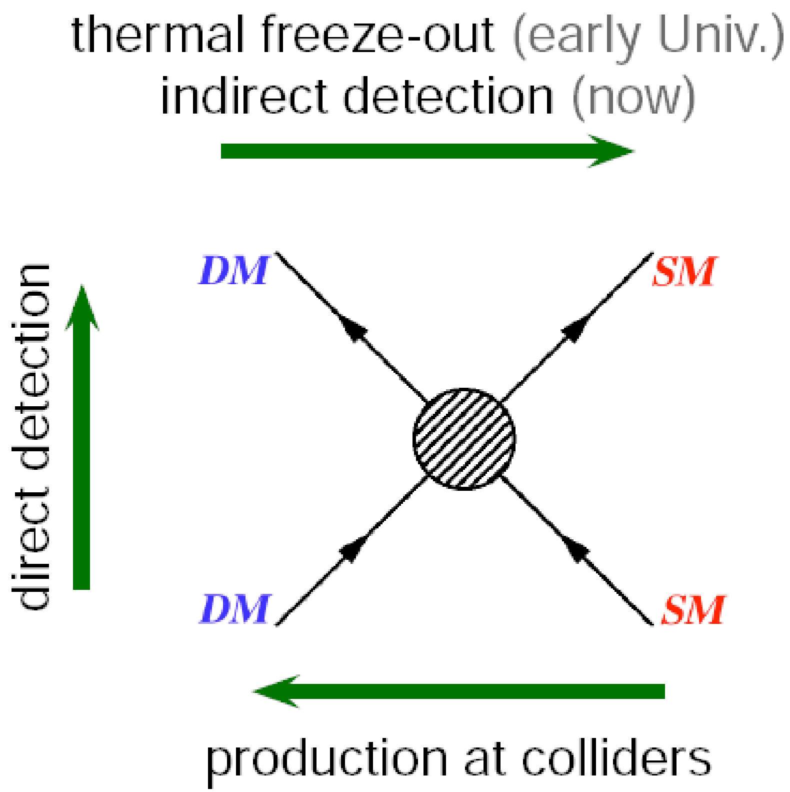
Composite dark matter explanation for high energy positron excess

- Any source of high energy positrons, distributed in galactic halo is simultaneously the source of gamma ray background, measured by FERMI/LAT.
- Not to exceed the measured gamma ray background the mass of decaying double charged particles should not exceed

$$M < 1 \text{ TeV}$$

COMPOSITE DARK MATTER CONSTITUENTS AT ACCELERATORS

Complementarity in searches for Dark Matter

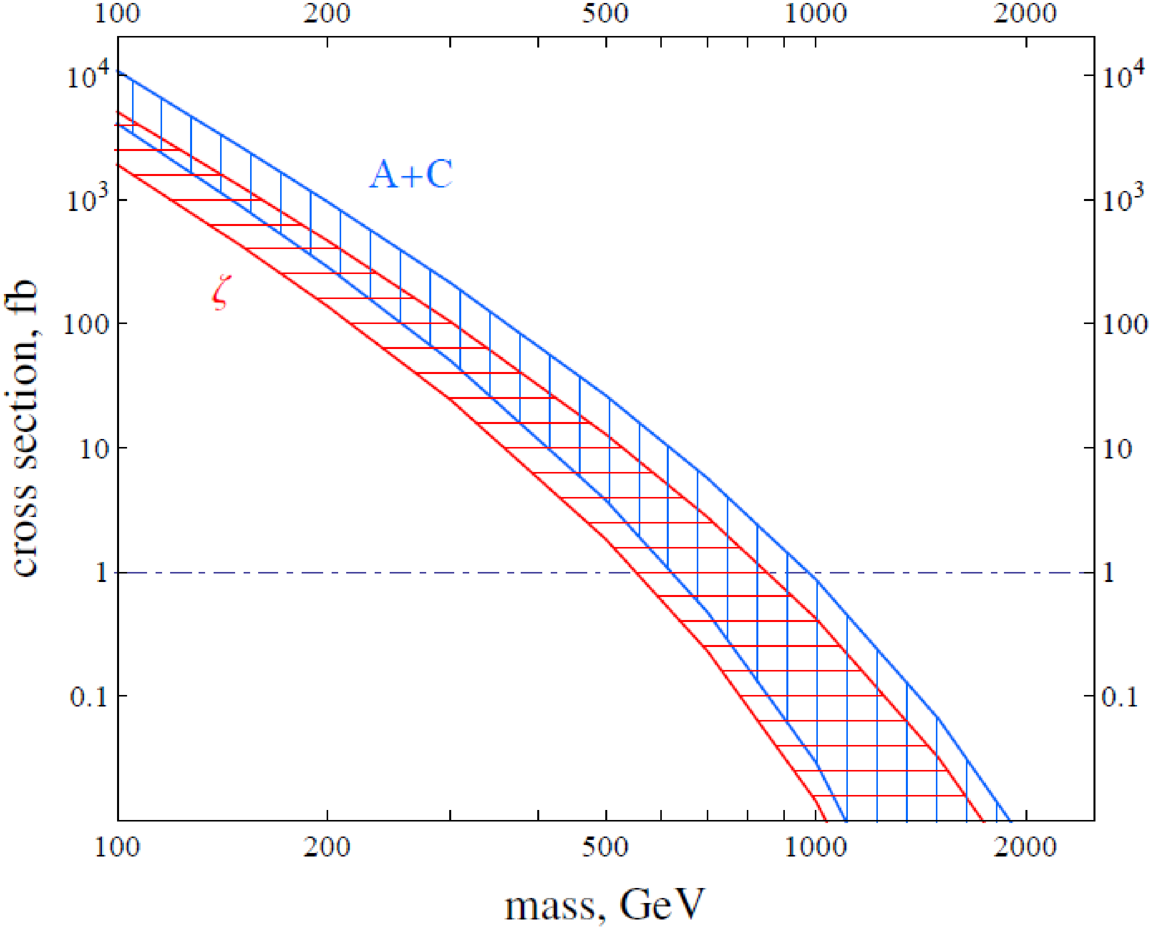


Usually, people use this illustration for complementarity in direct, indirect and accelerator searches for dark matter. However, we see that in the case of composite dark matter the situation is more nontrivial. We need charged particle searches to test dark atom model

Collider test for dark atoms

- Being the simplest dark atom model OHe scenario can not only explain the puzzles of direct dark matter searches, but also explain some possible observed indirect effects of dark matter. Such explanation implies a very narrow range of masses of (meta-) stable double charged particles in vicinity of 1 TeV, what is the challenge for their search at the experiments at the LHC.

LHC discovery potential for charged components of composite dark matter



The shaded strips correspond to production cross sections of technileptons and A,C leptons with Q=2 at 7 teV < $\sqrt{s}$ < 14 TeV

Search for multi-charge particles in the ATLAS experiment

Work is done in a frame of Multi-Charge Analysis Group

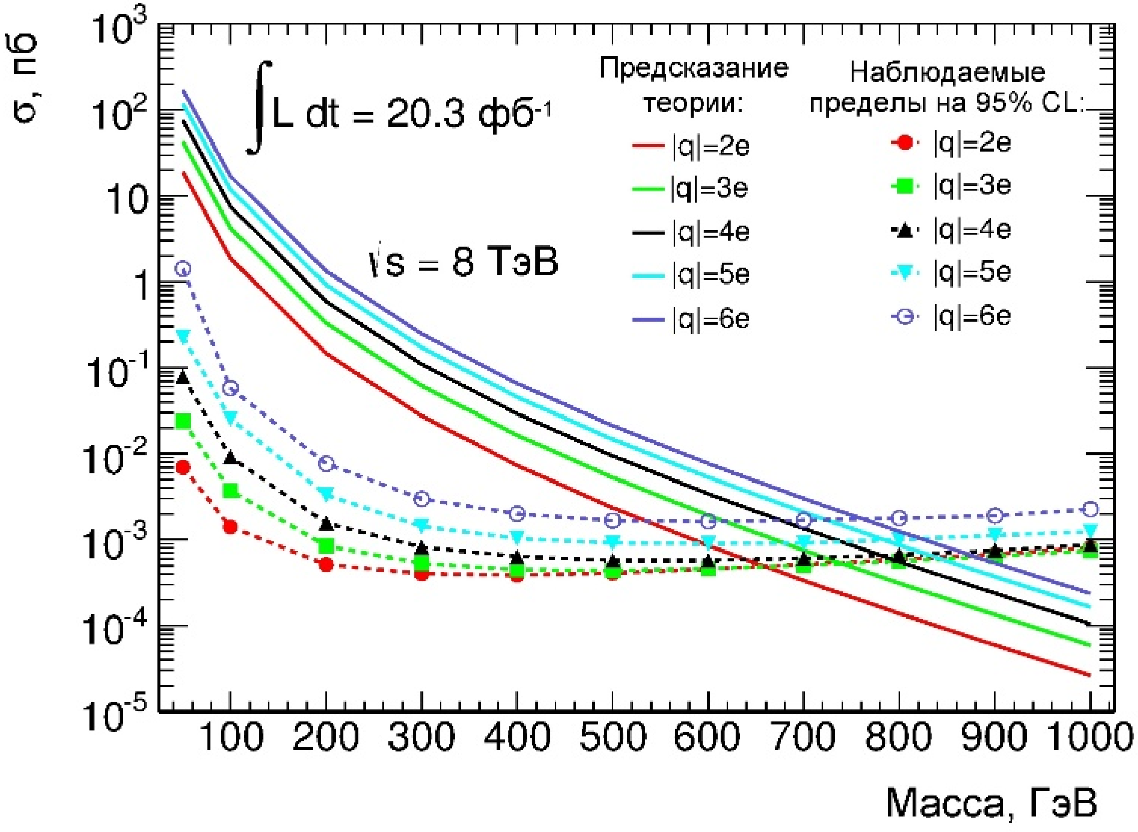
Search for Multi-charge Objects in *pp* collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector

K.M. Belotsky[a], O. Bulekov[a], M. Jüngst[b], M.Yu.Khlopov[a,h], C. Marino[c], P. Mermod[d], H. Ogren[e], A. Romaniouk[a], Y. Smirnov[a], W. Taylor[f], B. Weinert[g], D. Zieminska[e], S. Zimmermann[g]

[a]*Moscow Engineering Physics Institute*
[b]*CERN*
[c]*University of Victoria*
[d]*Oxford University*
[e]*Indiana University*
[f]*York University*
[g]*University of Bonn*
[h]*University of Paris*

Our studies favor good chances for detection of multi-charge species in ATLAS detector

Searches for multiple charged particles in ATLAS experiment



M>659 GeV for |q|=2e at 95% c.l. [Yu. Smirnov, PhD Thesis]

[ATLAS Collaboration, Search for heavy long-lived multi-charged particles in pp collisions at √s=8 TeV using the ATLAS detector, Eur. Phys. J. C 75 (2015) 362]

Experimentum crucis for composite dark matter at the LHC

Coming analysis of results of double charged particle searches at the LHC can cover all the range of masses, at which composite dark matter can explain excess of slow and high energy positrons, assuming the independent statistics In CMS and ATLAS experiments.

Data period	Estimated lower mass limit, GeV	
	ATLAS or CMS separately	ATLAS and CMS combined
2015–2016	1000	1110
2015–2018	1190	1300

Remind that composite dark matter can explain excess of low energy positrons at M=1.25 TeV and high energy positrons at M<1 TeV.

Conclusions

- New stable nonsingle charge particles (from magnetic monopoles to millicharged particles) can appear in extensions of Standard Model.

- Double charged particles can exist around us, bound within neutral « atomic » states – dark atoms.

- Composite dark matter can be in the form of nuclear interacting O-helium « atoms ». Their binding with nuclei in underground detectors possess annual modulation and can explain positive results of DAMA/NaI and DAMA/LIBRA experiments and controvrsial results of other groups.

- Indirect effects of composite dark matter can explain the observed excess of low energy and high energy positrons. This explanation is possible only if mass of double charged particles doesn't exceed the 1 TeV range.

- The crucial test for these indirect effects of composite dark matter and its constituents is possible in direct search for stable double charged particles at the LHC.