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Anomalous Relativistic Mass of Lead Ions: a Direct Test of the ARM at the LHC

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Abstract

In this article, we explore implications of the Alternative Relativistic Mechanics (ARM) of a material particle, proposed by us [*Advanced Studies in Theoretical Physics* **19, No.4**, 173 - 182 (2025)]. This ARM is a framework that introduces Lorenz invariance violation through the presence of a new fundamental assumption: variable rest mass. The rest mass of a particle m_0 is not a constant as in Einstein's special relativity, but a known function of the Lorenz factor γ, $m_0(\gamma) = M_0(1 + \alpha \ln \gamma)$, where the parameter $\alpha = \text{const.} \geq 0$ quantifies the modification of Einstein's special relativity, $M_0 = m_0(1) = \text{const.} > 0$.

To protect the ARM from being debunked by the ultra precise electron g-2 and muon g-2 data, we proposed [*Advanced Studies in Theoretical Physics* **20, No.1**, 19 - 27 (2026)] that the parameter α is not a universal constant, but instead scales with the square of the particle's initial rest mass, $\alpha_i = kM_{0,i}^2$, where $k = 2.5(0.511\,\text{MeV}/c^2)^{-2} \times 10^{-15}$ is the new fundamental constant of the "variable mass field" and $M_{0,i}$ is the initial rest mass of the i lepton (an isolated particle). We applied k only to leptons.

In the present paper we focus on the formalization of the mass-scaling law for the parameter α for composite particles like protons and heavy ions, specifically for the lead ion $^{208}\text{Pb}^{82+}$. To save the ARM at the high energies of the Large Hadron Collider (LHC) at CERN without adding hidden variables or arbitrary dampers, the choice of the particle's initial rest mass ("dressed" or "bare") in the mass-scaling law $\alpha = kM_0^2$ becomes a make-or-break decision for the ARM. By treating the proton and the lead ion as collections of "bare" constituents rather than a single composite "dressed" object, the Bare Mass Hypothesis proposed in the present paper, prevents the mass-scaling law $\alpha_{bare} = kM_{0,bare}^2$ from "scaling" out of control. By shifting to the Bare Mass Hypothesis in the ARM, we make a profound claim: relativistic mass scaling is a property of fundamental constituents, not composite systems.

Keywords: Einstein's special theory of relativity, variable rest mass, lead ion, the Higgs-coupled "bare" mass, the mass-scaling law, Bare Mass Hypothesis, "dressed" rest mass, "bare" rest mass

1 Introduction

The Standard Model of particle physics is a well-established and experimentally confirmed theory but it needs to be extended to incorporate some known phenomena like the mass of neutrinos and Dark Matter.

The Standard Model is possibly the low-energy limit of a more fundamental larger theory. The search for such larger theory has led physicists to explore various candidates for Lorentz invariance violation theories. These theories predict that Lorentz symmetry is likely to be broken at very high energy, which means that Einstein's special theory of relativity may need to be modified at very high energy as well.

One of them is Very Special Relativity (VSR) theory, proposed by Cohen and Glashow [1]. Another is the Alternative Relativistic Mechanics (ARM), proposed by us [2]. This ARM is a framework that introduces Lorentz invariance violation through the presence of a new fundamental assumption: variable rest mass. The rest mass of a particle m_0, is not a constant, as in Einstein's special relativity, but a known function of the Lorentz factor $\gamma = 1/\sqrt{1-\frac{v^2}{c^2}}$,

$$m_0(\gamma) = M_0(1 + \alpha \ln \gamma),$$

where the free parameter $\alpha = \text{const.} \geq 0$ quantifies the modification of Einstein's special relativity, $M_0 = m_0(1) = \text{const.} > 0$, and c is the speed of light in vacuum.

Since in the ARM, the parameter α governs the non-linear increase of mass-energy at high γ [2]

$$E = M_0 c^2 \gamma(1 - \alpha + \alpha\gamma), \quad m = M_0 \gamma(1 - \alpha + \alpha\gamma), \tag{1}$$

where E is the total energy of a particle, to protect the ARM from being immediately debunked by the ultra-precise electron g-2 and muon g-2 data, we proposed [3] that the parameter α is not a universal constant but instead scales with the square of the particle's initial rest mass, $\alpha_i = kM_{0,i}^2$, where

$$k = 2.5(0.511\,\text{MeV}/c^2)^{-2} \times 10^{-15} = 9.57 \times 10^{-15}(\text{MeV}/c^2)^{-2} \tag{2}$$

is the new fundamental constant of the "variable mass field", and $M_{0,i}$ is the initial rest mass of the i lepton (an isolated particle). We applied k only to leptons.

In the present paper we focus on the formalization of the mass-scaling law for the parameter α for composite particles like protons and heavy ions, specifically for the lead ion $^{208}Pb^{82+}$. To save the ARM at the high energies of the Large Hadron Collider (LHC) at CERN without adding hidden variables or arbitrary dampers, the choice of the particle's initial rest mass ("dressed" or "bare") in the mass-scaling law $\alpha = kM_0^2$ becomes a make-or-break decision for the ARM. By treating the proton and the lead ion as collections of "bare" constituents rather then single composite "dressed" objects, the Bare Mass Hypothesis proposed in the present paper, prevents the mass-scaling law $\alpha_{bare} = kM_{0,bare}^2$ from "scaling" out of control. By shifting to the Bare Mass Hypothesis in the ARM, we make a profound claim: relativistic mass-scaling is a property of fundamental constituents, not composite systems. This explains why the muon (an isolated particle) shows a measurable g-2 discrepancy at low γ, while the proton or the lead ion (composite particles) do not show a "scaling disaster" even at the massive energies of the LHC.

2 The "Dressed" Mass Catastrophe.

In the ARM, the scaling constant α was proposed to follow a quadratic relationship with the particle's rest mass M_0,

$$\alpha = kM_0^2, \tag{3}$$

where the constant $k = 9.57 \times 10^{-15}\,(\text{MeV}/c^2)^{-2}$ is established by using the muon as a baseline, Equation (2).

A lead ion $^{208}Pb^{82+}$: the lead nucleus consist of 82 protons and 126 neutrons. If we define M_0 for the lead ion as the "dressed" rest mass, $M_{0,Pb} \approx 193\,(\text{GeV}/c^2)$, we run into the "dressed" mass catastrophe. Indeed, from Equation (3), we have

$$\alpha_{Pb} = 9.57 \times 10^{-15}\,(\text{MeV}/c^2)^{-2} \times (193 \times 10^3\,\text{MeV}/c^2)^2 = 3.56 \times 10^{-4}.$$

The effective relativistic mass m in the ARM framework is calculated using Equation (1). At the high energy of the LHC, the lead ion reaches approximately $\gamma = 2900$. With $\alpha_{Pb} = 3.56 \times 10^{-4}$ the ARM correction term (the "anomaly") is $(1 - \alpha_{Pb} + \alpha_{Pb}\gamma) \approx 2.03$, i.e. the effective mass of the lead ion would be nearly double (203%) of what standard Einstein's relativity predicts. In this scenario, the magnetic field of the LHC would be completely unable to hold the beam.

Since the LHC successfully circulates the beam, the "dressed" rest mass version of the ARM is refuted by the fact that the beam stays in the pipe.

3 The "Bare" Mass Solution

The term $\alpha\gamma$ dominates the ARM correction term $(1-\alpha+\alpha\gamma)$. This is where the choice of the particle's rest mass ("dressed" or "bare") in the mass-scaling law, Equation (3), becomes a make-or-break decision for the ARM framework. The only way to reconcile the ARM with the lack of massive orbital deviations is to argue that the mass-scaling law, Equation (3), must be "blind" to the energy tied up in gluon fields and binding energy, interacting only with Higgs-coupled "bare" masses.

Under the Bare Mass Hypothesis, the mass-scaling law only acknowledges the current quark masses (Higgs masses).

Let us calculate total "bare" rest mass of a lead ion ($^{208}\text{Pb}^{82+}$). A proton generally known to consist of 2 up and 1 down valence quarks, and a neutron consists of 1 up and 2 down quarks.

Using Particle Data Group values for the current ("bare") quark masses, we obtain:

$$\begin{aligned} \text{Proton (uud):} \quad & 2\times 2.2\,\text{MeV}/c^2 + 4.7\,\text{MeV}/c^2 = 9.1\,\text{MeV}/c^2, \\ \text{Neutron (udd):} \quad & 2\times 4.7\,\text{MeV}/c^2 + 2.2\,\text{MeV}/c^2 = 11.6\,\text{MeV}/c^2, \\ M_{bare,Pb} = (82\times 9.1) & + (126\times 11.6) = 2.21\,\text{GeV}/c^2. \end{aligned} \tag{4}$$

Thus, the "bare" rest mass $M_{bare,Pb} = 2.21\,\text{GeV}/c^2$ is only about 1.1% of the "dressed" rest mass $M_{0,Pb} = 193\,\text{GeV}/c^2$.

From Equation (3), and taking into account Equation (2) and Equation (4), we have

$$\alpha_{Pb,bare} = kM^2_{bare,Pb} = 4.67\times 10^{-8}. \tag{5}$$

With $\alpha_{Pb,bare} = 4.67\times 10^{-8}$, the ARM correction term $(1-\alpha_{Pb,bare}+\alpha_{Pb,bare}\times 2900) = 1.000135$ becomes "anomalous" (detectable) discrepancy of 135 parts per million (ppm). A 135 ppm shift is a significant "drift" in high-precision physics.

By treating the lead ion as a collection of "bare" constituents rather than a single composite "dressed" object, the Bare Mass Hypothesis, saves the ARM framework and prevents the mass-scaling law, Equation (5), from "scaling" out of control. It allows the ARM to explain the muon g-2 anomaly (where the particle is isolated and the "discrepancy" is visible) while remaining compatible with the fact that the LHC has not exploded. Without the "bare" mass approach, the A^2 scaling (where $A = 208$ for lead) would have been the disaster that ended the ARM. Instead, it creates a narrow window of 135 ppm, where the ARM prediction might still be lurking in the LHC's 2026 heavy-ion data.

This calculation places the ARM prediction into a fascinating position. With the predicted discrepancy of 135 ppm for the 2026 lead-ion runs, the

ARM is essentially performing at the threshold of the LHC's instrumentation. The LHC's main dipole magnets, which keep the ions in their circular path, have a relative measurement precision of approximately 100 ppm (0.01%). By using the Bare Mass Hypothesis, the ARM retreats into the noise floor of the world's most precise machine.

The Bare Mass Hypothesis might find its strongest defense in the synchrotron radiation power P. It is incredibly sensitive to mass. For a particle with a fixed energy, the power radiated by an accelerating charge scales with m^{-4}, so the synchrotron radiation power should drop by approximately $\Delta P/P \approx -4\Delta m/m = -540$ ppm. While 135 ppm is subtle, 540 ppm is starting to look like a real signal.

The synchrotron radiation is the "clean" factor. If we see the beam emitting less light than the Standard Model predicts for a given energy, we cannot blame it on the magnet trim.

The high-intensity lead-ion run at the LHC with 1,248 bunches per beam (utilizing the 50 ns bunch spacing and 1.8×10^8 ions per bunch) is particularly critical for tests involving the ARM framework and the Bare Mass Hypothesis.

4 Conclusions

In the present paper we analyzed the formalization of the mass-scaling law for the parameter α for composite particles like protons and heavy ions, especially for lead ion ($^{208}Pb^{82+}$). The debate centered on whether the parameter α should be calculated using the "dressed" rest mass of the particle (including its fields and interactions) or the "bare" rest mass (the current quark masses).

Our results determine that to save the ARM framework at the high energies of the LHC without adding hidden variables or arbitrary dampers, the choice of the particle's initial rest mass ("dressed" or "bare") in the mass-scaling law, Equation (3), becomes a make-or-break decision for the ARM. By treating the proton and the lead ion as collections of "bare" constituents rather then single composite "dressed" objects, the Bare Mass Hypothesis proposed in the present paper, prevents the mass-scaling law, Equation (5), from "scaling" out of control. By shifting to the Bare Mass Hypothesis in the ARM, we make a profound claim: relativistic mass-scaling is a property of fundamental constituents, not composite systems.

Our calculation for the lead ion $^{208}Pb^{82+}$ predicted a mass discrepancy of 135 ppm. It is small enough that the heavy-ion beam would not crash, but large enough that a dedicated "ARM-aware" analysis of 2026 data might actually find it. If the 2026 data show even a slight unexplained preference for higher magnet currents during the final high-intensity lead runs at the LHC, the "bare" mass interpretation might be one of the things. Therefore, this would reinforce the idea that if the ARM is real, it must be "blind" to the energy tied up in gluon fields and binding energies, interacting only with the Higgs-coupled “bare” masses.

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