Tests of new physics at very high energy

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Data at ultra-high energy or just below this scale are now being carefully analyzed by several teams and collaborations.

The relation between particle dynamics at these energies and standard physics such as tested at accelerators is clearly a crucial question.

We present an updated discussion of the possible role of new physics leading to departures from natural extrapolations. Possible deviations from conventional relativity, quantum field theory, particle symmetries and other standard fundamental principles are given particular attention and new experimental tests are suggested.

The possible interaction between this problematics and Cosmology and other aspects of fundamental Physics is also discussed, considering in particular : i) interrogations and open questions about BICEP2 and Planck data and analyses ; ii) vacuum structure and dynamics, space-time...

=> High-energy cosmic rays and UHECR, symmetries and particle properties at ultra-high energy, pre-Big Bang, ultimate constituents, space-time geometry, interaction with quantum field theory, superbradyons and vacuum…

=> A possible interaction with quantum mechanics ?

SOME REMINDERS AND OPEN QUESTIONS

(LSV = Lorentz symmetry violation
VHE = very high energy
UHE = ultra-high energy
UHECR = ultra-high energy cosmic rays
QFT = quantum field theory)

Do Planck units really make sense ? Behind this concept is the standard idea that the fundamental laws of Physics can be smoothly extrapolated up to Planck energy and down to the Planck distance and time scales. But is this assumption really correct ?

Planck units (*h* = Planck constant, *G* = gravitational constant) :

- Squared Planck length

$$l_P^2 = h\,G\,(2\pi c)^{-3}$$

-Squared Planck energy

$$E_P^2 = h\,c^5\,(2\pi G)^{-1}$$

etc… But do standard laws of Physics (including gravitation) really apply near these scales ? =>

How to test this hypothesis ?

Explore a possible energy-dependence of the effective values of *c*, *h*, *G*… ?

Ultra-high energy cosmic-ray (UHECR) experiments would be particularly sensitive to an energy-dependent value of *c* (f.i. spontaneous decays or the converse effect)

A transition energy appears for UHECR when adding to standard kinematics a Lorenz-violating (LSV) term

ΔE : $E^2 = p^2 c^2 + m^2 c^4 - (\Delta E)^2$

where ΔE increases with energy => a transition energy E_{trans} is present when ΔE becomes larger than $m c^2$

A possible scenario based on the existence of a transition scale E_{trans} at VHE : above E_{trans} , standard laws would start becoming less and less dominant and new (preonic ?) Physics would replace the conventional Particle Physics principles.

If such a phenomenon occurs at the 10^{20} eV scale, and if ΔE varies like E^2, then one has $\Delta E \sim 10^5 E^2 / E_{planck}$ => $a \sim 10^5$ strength at Planck scale when looking at some LSV patterns inspired by condensed-matter Physics => what may happen around the 10^{17} GeV scale?

How to experimentally test the possible existence of a E_{trans} scale for Particle Physics well below the Planck scale E_{Planck}?

How to explore and detect possible deviations from the fundamental standard laws of Physics as energy increases and the relevant distance scale becomes smaller ?

UHECR signatures ?

COMBINE PARTICLE PHYSICS WITH COSMOLOGY AND OTHER FIELDS

The existence of a transition energy scale E_{trans} would also imply a transition in the evolution of the Universe

=> nonstandard (or just new) phenomena in WMAP, Planck, BICEP2… can be signatures of new Physics

Similarly, what about vacuum structure and possible deviations from standard QFT ? Influence on particle propagation

Related papers :

arXiv:astro-ph/9601090 , arXiv:astro-ph/9610089, arXiv:hep-ph/9610474 , arXiv:physics/9702026 , physics/9704017 arXiv:09020994 , arXiv:0905.4146 , arXiv:0908.4070 , arXiv:0912.0725 , arXiv:1011.4889 , arXiv:1110.6171 , arXiv:1202.1277 - HEP 2011 EPS-HEP2011_479 and 390 (PoS) - My contributions to ICFP 2012 - ICNFP 2013 and references therein - Recent papers *Planck data, spinorial space-time and asymptotic universe* (I) and (II), mp_arc 13-33 and 14-60

The poster also included particular references to the articles :

The Planck Collaboration, Planck 2013 results. XXIII. Isotropy and statistics of the CMB, arXiv:1303.5083

The BICEP2 Collaboration, *BICEP2 I: Detection Of B-mode Polarization at Degree Angular Scales*, first version arXiv:1403.3985v1 and last version *Phys. Rev. Lett.* 112, 241101 (2014)

L. Gonzalez-Mestres, paper included in the material of the Plenary Session.

TOGETHER WITH PLANCK, HAS THE BICEP2 RESULT PROVIDED A DOUBLE EXPERIMENTAL EVIDENCE (PRIVILEGED SPACE DIRECTION + CMB B-MODES) FOR THE SPINORIAL SPACE-TIME (SST) SUGGESTED IN 1996-97 (arXiv:hep-ph/9610474,)?

SEE MY PLENARY SESSION TALK AND MATERIAL

The BICEP2 Collaboration defined its detector as :

"…a Cosmic Microwave Background (CMB) polarimeter specifically designed to search for the signal of inflationary gravitational waves in the B-mode power spectrum" But why only this scenario ?

Planck, arXiv:1303.5083 writes:

Indeed, when the power spectra of two hemispheres defined by a preferred direction are considered separately, one shows evidence for a deficit in power, while its opposite contains oscillations between odd and even modes that may be related to the parity violation and phase correlations also detected in the data.

Planck comment on "anomalous features": "One is an asymmetry in the average temperatures on opposite hemispheres of the sky (…), with slightly higher average temperatures in the southern ecliptic hemisphere and slightly lower average temperatures in the northern ecliptic hemisphere. This runs counter to the prediction made by the standard model that the Universe should be broadly similar in any direction we look." (ESA-Planck, 22

=>Together with parity violation, the existence for each observer of a privileged space direction as predicted from the spinorial space-time may have generated the anomaly recently confirmed by Planck. Parity violation can break isotropy in the presence of a privileged space direction.

THE SPECIFIC ROLE OF THE SST

For each space-time position spinor ξ it is possible to find a representation of (cosmic) sigma matrices such that ξ is an eigenstate of one of them (f.i. σ_z)
=> σ_z can define a privileged space direction from the position of the space-time spinor ξ => Each point of the cosmic space-time may keep a track from the ξ = 0 origin of the Universe, through a privileged space direction.

SIMULTANEOUSLY , THE EXISTENCE OF A PRIVILEGED SPACE DIRECTION (PSD) OF PURELY GEOMETRIC ORIGIN IN THE SST IS EXPECTED TO LEAD IN THE EARLY UNIVERSE TO VECTOR PERTURBATIONS ABLE TO GENERATE THE PRIMORDIAL *B*-MODES IN THE POLARIZATION OF THE COSMIC MICROWAVE BACKGROUND RADIATION POSSIBLY DETECTED BY BICEP2 => A DOUBLE EVIDENCE ? => SEE THE MATERIAL OF MY PLENARY SESSION TALK. IF SO, CAN HIGH-ENERGY COSMIC RAYS BE SENSITIVE TO THE PSD ?

THE SPINORIAL SPACE-TIME WOULD ALSO RAISE THE BASIC QUESTIONS OF VACUUM STRUCTURE, ULTIMATE CONSTITUENTS OF MATTER AND PRE-BIG BANG

COSMIC TIME - Extracting from a cosmic spinor ξ the scalar $|\xi|^2 = \xi^\dagger \xi$ where the dagger stands for hermitic conjugate, a positive cosmic time $t = |\xi|$ (or a function of $|\xi|$) is defined => naturally expanding universe, arrow of time.

=> ORIGIN AND CONTEXT OF THIS EXPANDING UNIVERSE ?

A SUPERBRADYONIC VACUUM CAN SOLVE THE COSMOLOGICAL CONSTANT PROBLEM (SUPERBRADYONS = SUPERLUMINAL PREONS)

IN A SUPERBRADYONIC VACUUM, THE STANDARD SCALAR FIELDS AND HARMONIC-OSCILLATOR ZERO MODES WOULD NOT BE NECESSARILY CONDENSED IN THE ABSENCE OF SURROUNDING STANDARD MATTER

=> POSSIBLE EFFECTS ON COSMIC-RAY PROPAGATION ?

POSSIBLE ROLE OF HIGH-ENERGY PHYSICS

(COSMIC RAYS, ACCELERATOR EXPERIMENTS)

- COSMIC-RAY EXPERIMENTS CAN SEARCH FOR SIGNATURES OF E_{trans} AND OF A NEW VACUUM STRUCTURE AT COSMIC SCALE, AS WELL AS FOR POSSIBLE VIOLATIONS OF BASIC PRINCIPLES OF CONVENTIONAL PHYSICS : LORENTZ SYMMETRY, QUANTUM MECHANICS, CONSERVATION LAWS, STANDARD SYMMETRIES… AND FOR NEW PARTICLES, HEAVY OBJECTS…

- EXPERIMENTS AT ACCELERATORS CAN SEARCH MORE WIDELY FOR NEW PARTICLES AND POSSIBLE DEPARTURES FROM STANDARD PHYSICS

IN THE SST APPROACH, SPACE TRANSLATIONS ARE GIVEN BY SU(2) TRANSFORMATIONS ACTING ON THE COSMIC SPINORS => A COMPACT GROUP ESCAPING STANDARD NO-GO THEOREMS FOR SYMMETRIES => ALTERNATIVES TO STANDARD SUPERSYMMETRY => POSSIBLE NEW FAMILIES OF PARTICLES

=> WOULD POSSIBLY INCLUDE SST NATURAL PREONIC BOUND STATES WITH SPIN 0, 1/2, 1, 3/2, 2, 5/2… => SEARCH FOR "ELEMENTARY" SPIN-3/2 FERMIONS, NEW SPIN-2 GAUGE FIELDS, SPIN 5/2…

PRIVILEGED SPACE DIRECTION => POSSIBLE TESTS OF MOMENTUM CONSERVATION ?

- INTERNAL STRUCTURE AND INTERACTIONS OF "ELEMENTARY" FERMIONS AT VERY SHORT DISTANCES AND HIGH ENERGIES

- ARE THE "ELEMENTARY" FERMIONS PURE SPIN EIGENSTATES ?

- SEARCH FOR SMALL OSCILLATIONS OF FERMION SPIN ? AT ALL ENERGIES, AS THE SST IMPLIES LSV

PRIVILEGED SPACE DIRECTION AND COSMIC RAYS

SEARCH FOR A SIGNAL CORRELATED WITH THE PRIVILEGED DIRECTION FOUND BY PLANCK

CONSIDER POSSIBLE ANISOTROPIC VIOLATIONS OF STANDARD PRINCIPLES, LAWS, SYMMETRIES…

PARTICULAR ATTENTION TO COSMIC RAYS OF THE MOST DISTANT ORIGIN

COSMIC SST AND STANDARD-MATTER SYMMETRY PATTERNS

- **COSMIC :** SST SU(2) combined with "ultimate" internal symmetries => - **POSSIBLE EXACT UNIFICATION => a new alternative to supersymmetry ?**

- **STANDARD MATTER :** conventional symmetries (including Lorentz) and supersymmetries can be just low-energy limits => **replaced by the cosmic symmetries above E_{trans} ?**

GZK cutoff or maximum energy available at astrophysical sources ? The experimental situation is not yet clear.

A GZK-like cutoff would not exclude the existence of E_{trans} and of new physics above E_{trans} . Deformations of kinematics can fake the GZK cutoff => Further theoretical, phenomenological and experimental work required.

***Auger*, *arXiv* : 1307.0226, 1307.0324, 1307.3956, 1307.5059, 1308.0820, 1310.4620, 1406.2912, 1406.4038, 1407.3214, 1407.5919, 1408.1421…**

***Telescope Array*, *arXiv* : 1306.6138 (*Auger* + *T.A.* + *Yakutsk*), 1310.0647 (with *Auger*), 1404.5890, 1407.6145, 1408.1726…**

Satellite experiments can play a crucial role to improve our understanding of high-energy cosmic rays.

***JEM-EUSO* project : arXiv:1212.6520**

From a theoretical point of view, alternative cosmologies emphasize the extent of present uncertainties. Standard particle propagation in cosmic superbradyonic vacuum ? Vacuum inhomogeneities ?

COSMIC MICROWAVE BACKGROUND PHOTONS APPEAR TO NORMALLY PROPAGATE IN COSMIC VACUUM.

BUT UHECR HAVE MUCH SHORTER WAVELENGTHS : 10^{19} eV ~ 10^{-23} cm

=> CAN POTENTIALLY BE SENSITIVE TO THE ULTIMATE STRUCTURE OF THE PHYSICAL VACUUM IN COSMIC SPACE

=> A POSSIBLE ALTERNATIVE TO THE GZK MECHANISM, OR MORE GENERALLY A SOURCE OF NEW PHENOMENA

ALSO, QUARK DECONFINEMENT ?

BASIC LINK WITH FUNDAMENTAL QUANTUM MECHANICS

Quantum mechanics can also be violated or deformed at ultra-high energy. Anomalous commutation relations (f.i. between components of momentum) can produce observable effects in UHECR.

BUT THE SUPERBRADYONIC VACUUM CAN ALSO PLAY A ROLE IN THE FOUNDATIONS OF QUANTUM MECHANICS ITSELF

=> Possible role of the propagation of superluminal signals ?

The propagation of superluminal signals in vacuum was already tacitly assumed in the suggestion that standard scalar bosons and zero modes of harmonic oscillators are not permanently condensed in vacuum in the absence of surrounding standard matter (thus solving the cosmological constant problem). What, then, about the principles of quantum mechanics itself ?

For the present status of work on the principles of quantum mechanics and their interpretation, see the contributions on quantum entanglement to this conference.

In a superbradyonic vacuum, signals can propagate much faster than light. The natural limit being the superbradyonic critical speed c_s => a possible relation between quantum mechanics and the ultimate structure of standard particles ?

In the SST, spinorial wave functions also imply crossing the near past and future (local spinorial coordinates $\xi - \xi_0$ around the particle position ξ_0) => time does no longer have strict sense at such very small scales => possible measurable implications through basic quantum mechanics?

CONCLUSION

Particle Physics and Cosmology form a coherent and totally open field

=> Beyond standard patterns, alternative cosmologies appear to be closely associated to alternative particle physics that can potentially be tested by cosmic-ray and accelerator experiments

=> New approaches to quantum mechanics and quantum field theory ?