Tests of New Physics Beyond the Standard Model(s)

Session Highlights

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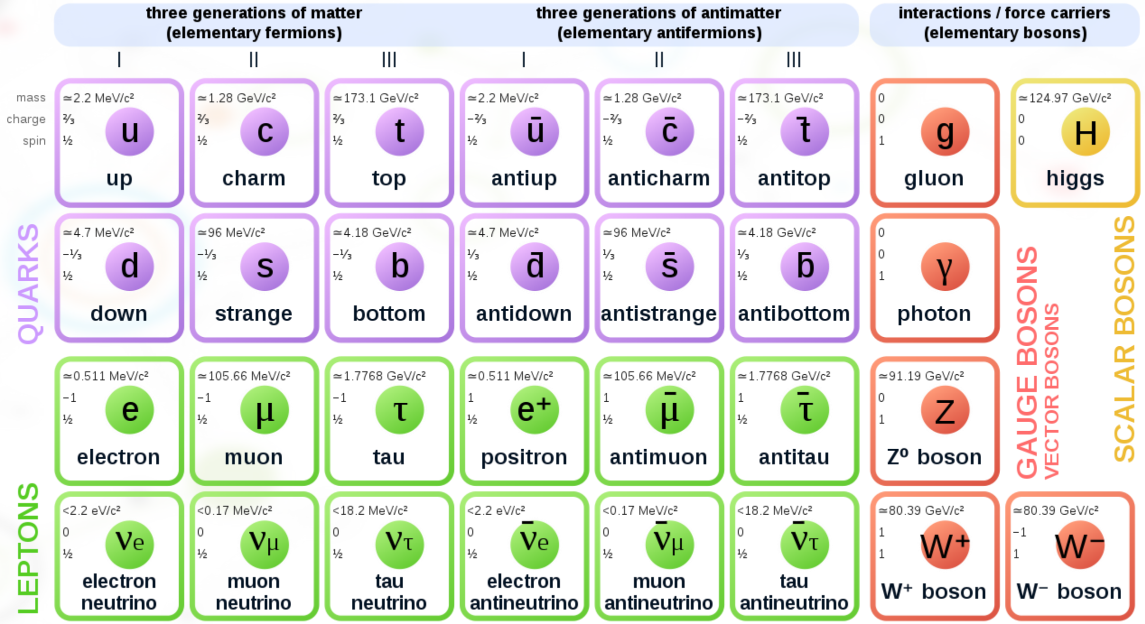
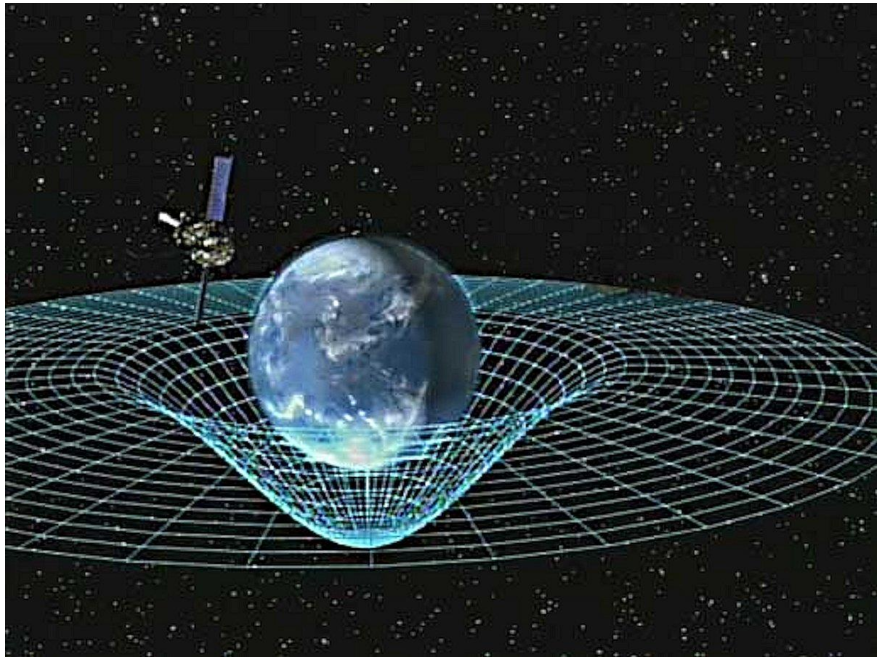
Standard Model(s) of Physics

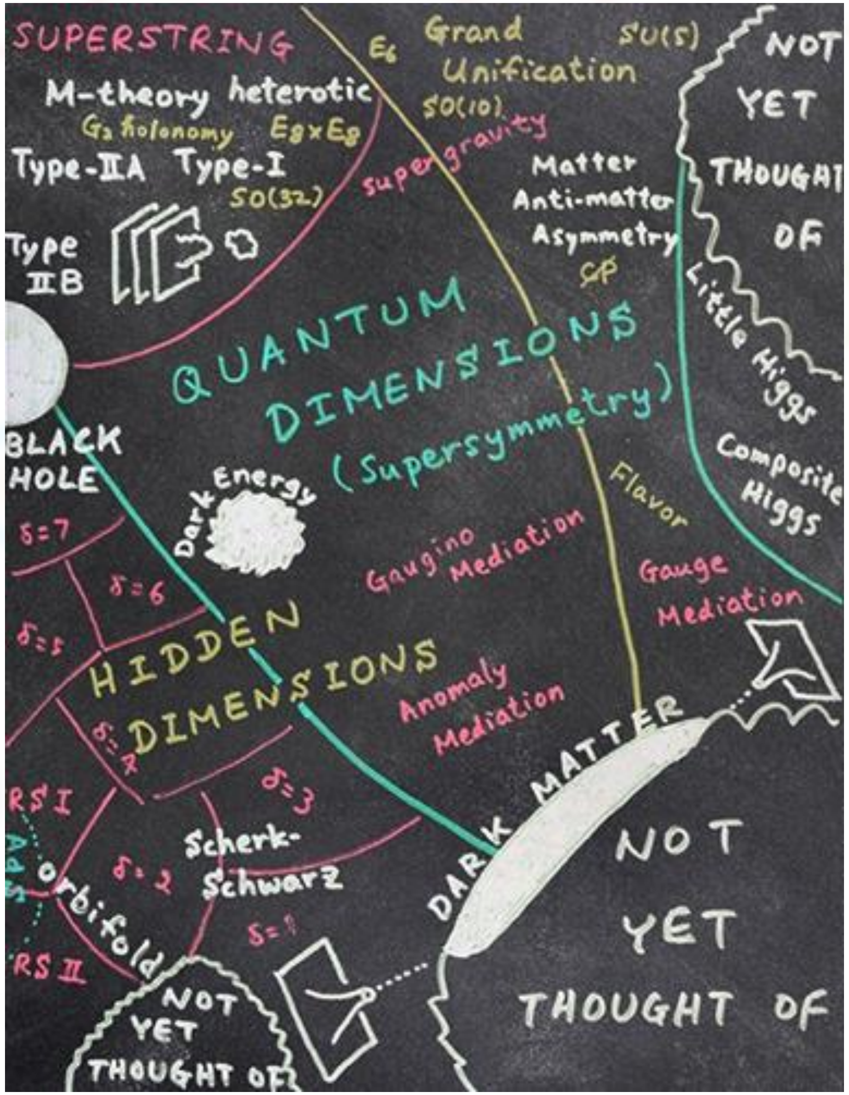
Standard Model of Elementary Particles



General Relativity



Experimental searches for New Physics



Challenging the boundaries of our present models

- Searches of new particles at colliders
- Precision measurements of particle properties
- Cosmic ray distribution and interactions
- Direct and indirect Dark Matter searches
- Astronomic observations in the multi-messenger era
- Neutrinos ($0\nu\beta\beta$, oscillations)
- Gravitational waves astronomy
- High-precision spectroscopy
- Time drift of fundamental constants

(the list continues ...)

Searches beyond the Standard Model(s) in FELLINI

- Searches for Lepton Flavour Universality violations
- Searches for vac. mag. biref. and axions
- Searches for violations to the Equivalence Principle

Lepton Flavour Universality

The Higgs particle has provided the ultimate experimental verification of the Standard Model. However, theoretical arguments and experimental observations point towards the existence of physics beyond the SM.

Recently a hint of New Physics come from a possible lepton flavour universality violation observed by the LHCb experiment in the decays $B^+ \rightarrow K^+ l^+ l^-$ and $B^0 \rightarrow K^{*0} l^+ l^-$ decays with a significance of 2.1 – 2.5 standard deviations.

These decays involving $b \rightarrow s l^+ l^-$ transitions, mediated by flavor-changing neutral currents, are suppressed in the SM, as they proceed only through amplitudes that involve electroweak loop diagrams.

The electroweak couplings of all three charged leptons are identical in the SM and, consequently, the decay properties are expected to be the same up to corrections related to the lepton mass, regardless of the lepton flavour.

These processes are sensitive to virtual contributions from new particles (for example z' boson or leptoquark), which could have masses that are inaccessible to direct searches for resonances, even at Large Hadron Collider experiments.

Probing LFU with Kaons

The same NP mediators explaining the observed flavour anomalies in B mesons can induce effects of lepton flavour universality violation in rare kaon decays as of $K^+ \to \pi^+\mu^+\mu^-$ and $K \to \pi^+e^+e^-$.

The weak form factor of these K decays can be parametrized at Next–to–Leading–Order (NLO) in Chiral Perturbation Theory (ChPT) as

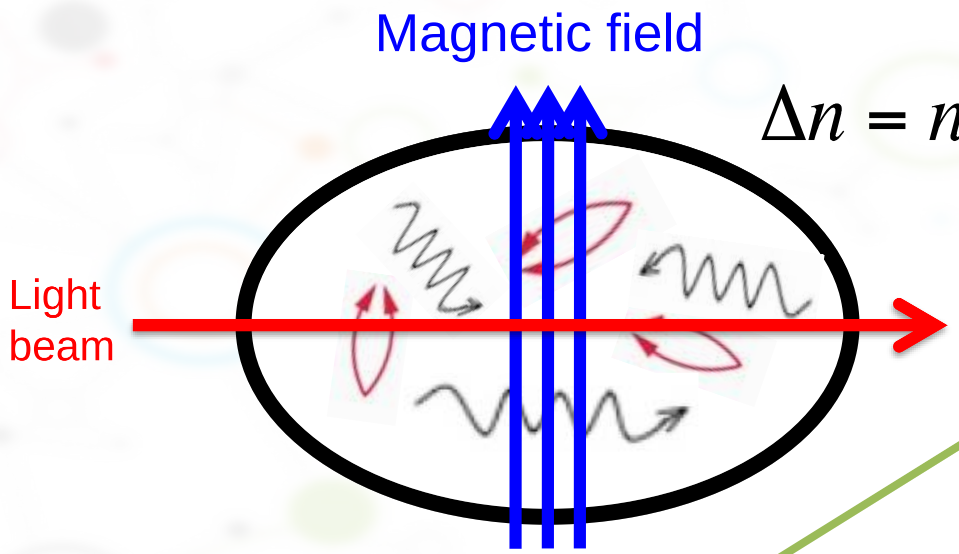
$$V_+(z) = a_+ + b_+ z + V_+^{\pi\pi}(z)$$

Where a_+ and b_+ are phenomenological constants, $V_+^{\pi\pi}(z)$ is a pion loop term and z is the transferred momentum.

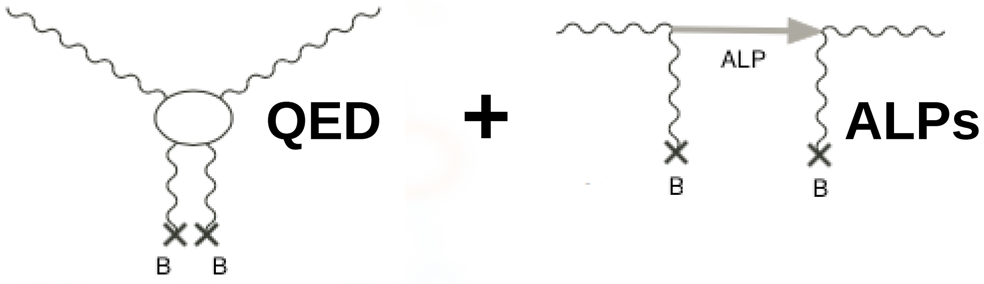
If Lepton Flavour Universality (LFU) is not violated, the parameters a_+ and b_+ must be identical for both the decays $K^+ \to \pi^+\mu^+\mu^-$ and $K \to \pi^+e^+e^-$.

Vacuum is structured and has properties that can be studied experimentally.

Light propagation in an external field



$$\Delta n = n_{\parallel} - n_{\perp}$$

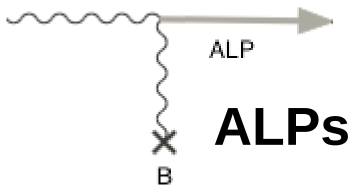


$\Delta n_{QED} = 3A_e B^2 = 4\times10^{-24}$ @ 1 T magnetic field

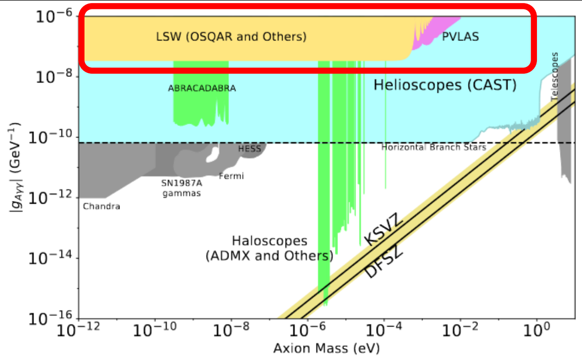
VACUUM MAGNETIC BIREFRINGENCE

$$\Delta\tilde{n} = \Delta n_B + i\Delta\kappa_B$$

BIREFRINGENCE DICHROISM



search for 'light' DM



Polarimetry

Experimental method

- Perturb with an external B field
- Probe with a (polarised) light beam
- Detect changes in the polarisation state

→

High magnetic field

Long optical path

High sensitivity polarimeter

→

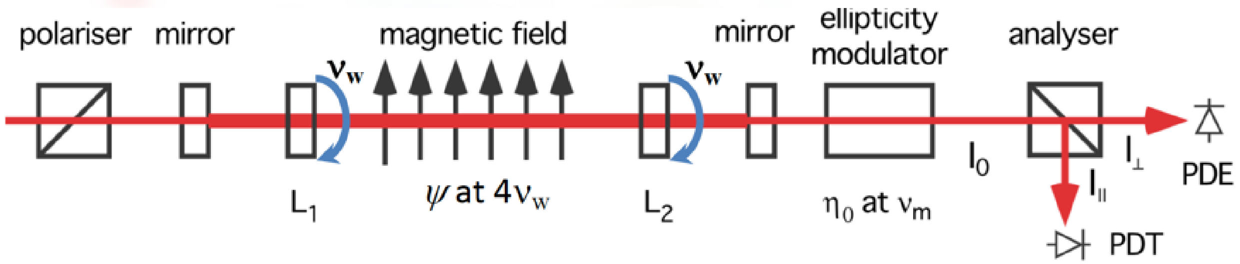
LHC dipole

Optical cavity

Signal Modulation

VMB@CERN

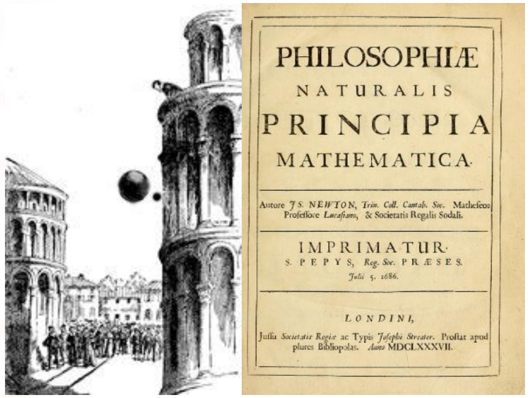
Method to modulate the expected signal using two co-rotating half waveplates inside an optical cavity



CRITICAL TASKS:

- Build a cavity around a LHC magnet and keep it aligned (noisy environment).
- Control the alignment of the optics inside the cavity to reduce systematics.

Galileo/Newton's universality of the free-fall

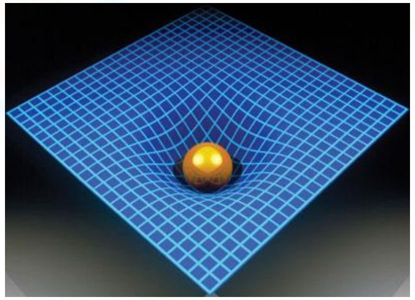


«The quantity of matter (...) arising from its density and bulk conjointly (...) that I mean hereafter under the name of body or mass. And the same is known by the weight of each body, for it is proportional to the weight, as I have found by experiments on pendulums very accurately made» [2]

$$m_i = m_g$$

(with m_i the inertial mass and m_g the (passive) gravitational mass)

Einstein's Equivalence Principle (EP)

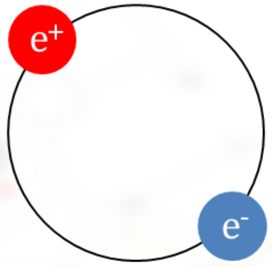


(1) Inertial and gravitational masses are equivalent (2) the result of any local non-gravitational experiment is independent of the velocity of the free-falling apparatus, and (3) the outcome of any local non-gravitational experiment is independent of where and when in the Universe it is performed.

EEP := **WEP** (Weak Equivalence Principle) + **LLI** (Local Lorentz Invariance) + **LPI** (Local Position Invariance)

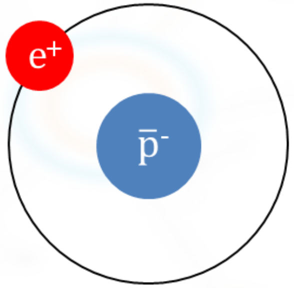
Consequences of the EP on metric theories of gravity

1. Spacetime is endowed with a metric
2. The free-fall trajectories of test bodies are geodesics of that metric
3. In local freely falling frames, the nongravitational laws of physics obey special relativity



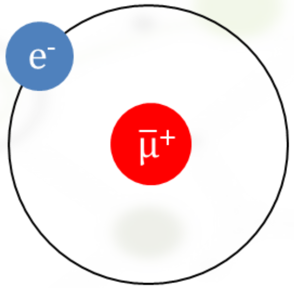
Positronium (Ps)

- short lifetime only in GS (142 ns)
- 50% of mass is antimatter
- first generation elementary system
- produced in large numbers @



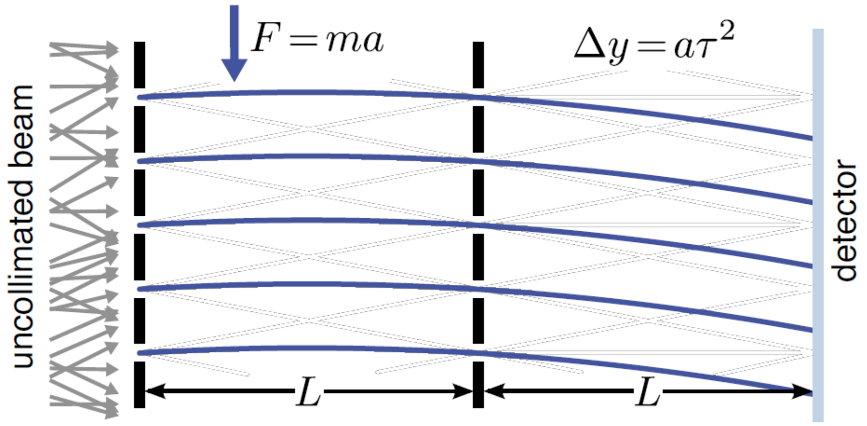
Antihydrogen ($\bar{H}$)

- only stable candidate
- 99.95% mass is in form of QCD binding E
- first generation, non-elementary system
- produced in small amounts only @



Muonium (Mu)

- short lifetime in all levels (2.2 us)
- 99.5% of mass is antimatter
- second generation elementary system
- produced in large numbers @



Study the possibility to probe the universality of thefree-fall by measuring Earth's gravitational acceleration with cold, long-lived Positronium atoms.