Seeking Lorentz Violation from the Higgs

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Lorentz transformations are a symmetry of our world!

So were galilean transformations, parity, CP...

Outline

- Overview of Lorentz Violation
- Lorentz Violation in the Higgs sector
  - Super-luminal Higgs
  - Sub-luminal Higgs
- Conclusion

Lorentz Violation

- In many sectors Lorentz symmetry has been tested to enormous precision.

- Early tests focused on high precision atomic physics measurements.

- However in many cases we have learned[1] that we can replace high precision by high energies.

[1] S. R. Coleman and S. L. Glashow, *Phys. Rev.* **D59** (1999) 116008

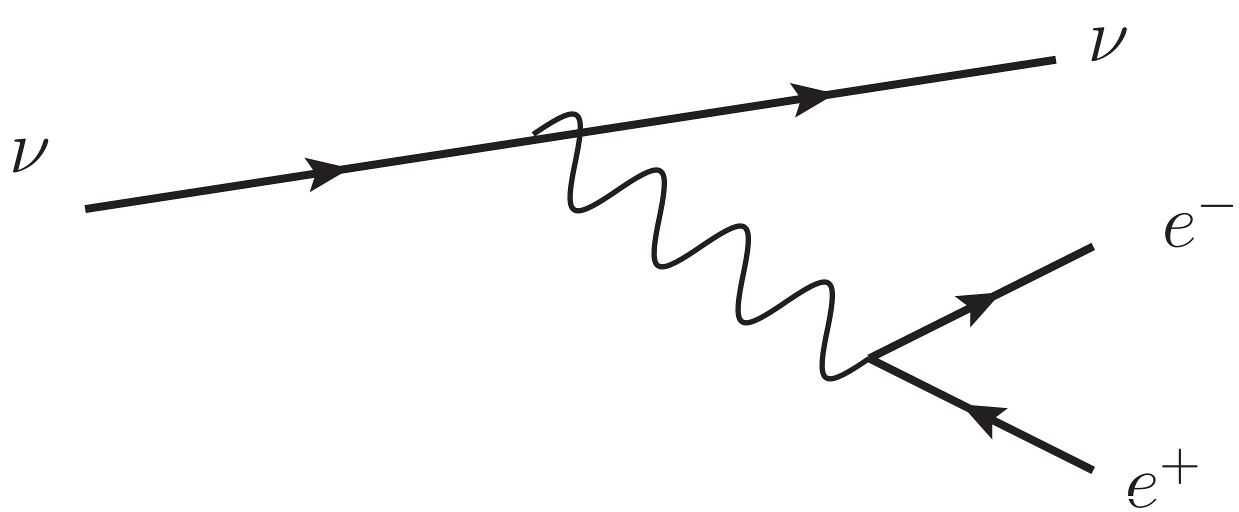
EFT

- Effects from lowest dimensional operators dominate.

- In many cases the only renormalizable interactions allowed by the symmetries are modifications to the kinetic term

Change in the dispersion relation → Forbidden processes become kinematically allowed

Faster than light Neutrinos



Neutrinos can Cherenkov radiate for energies above threshold

$$E_0 = 2m_e/\sqrt{v_\nu^2 - 1}$$

Rate for this process grows with energy

$$\Gamma \sim E^5 (v_\nu^2 - 1)^3$$

A. G. Cohen and S. L. Glashow, *Phys. Rev. Lett.* **107** (2011) 181803

Lorentz Violation in the Higgs sector

- Imposing rotational invariance there is a single dim 4 operator:

$$\mathcal{L}_{\rm LV} = \delta (n \cdot DH)^\dagger (n \cdot DH), \quad n^2 = 1$$

- Modifies Higgs dispersion relation

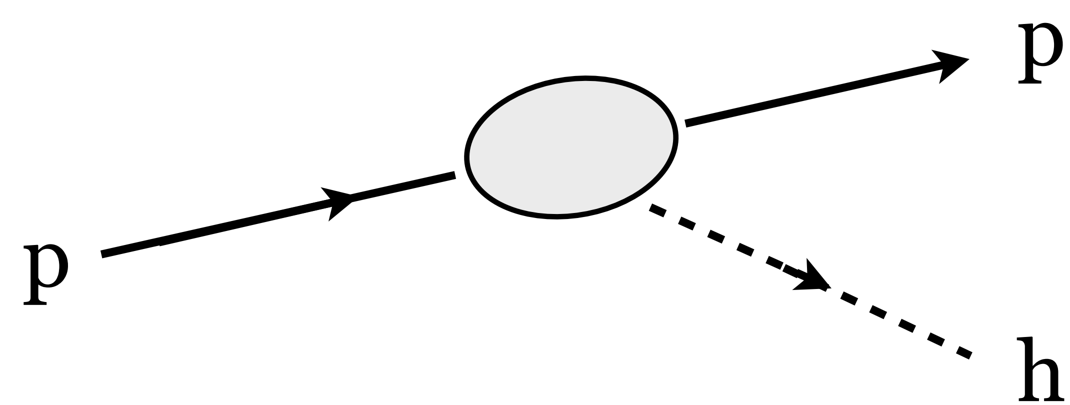
$$E^2 = (1-\delta)p^2 + m^2 \qquad\qquad v_h = \frac{\partial E}{\partial p} = \frac{(1-\delta)p}{E}$$

- Also modifies propagation of longitudinal W's and Z's

Subluminal Higgs

$(\,\delta > 0\,)$

Higgs-strahlung

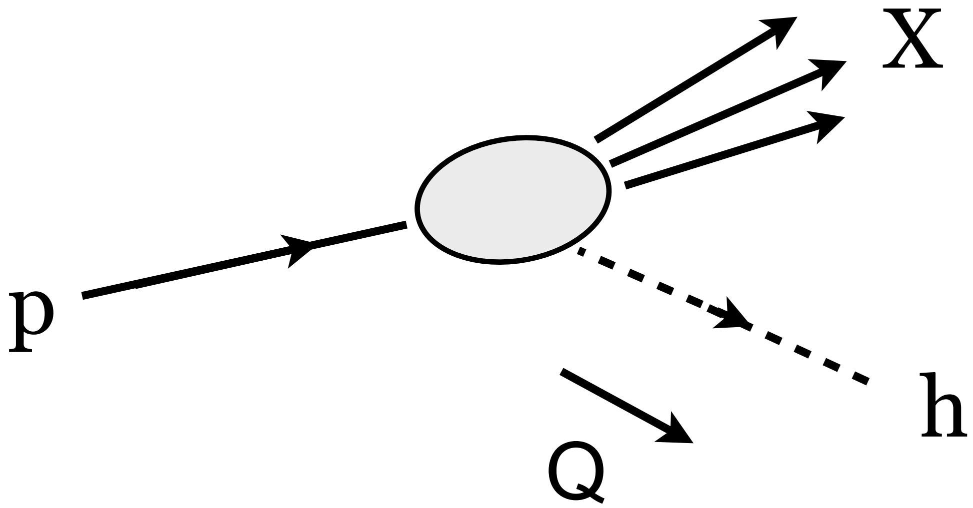


Threshold: $E_0 \approx m_h/\sqrt{\delta}$

UHECR

Ultra high energy cosmic rays: $E \sim 10^{20}$ eV

If E_0 is smaller than 10^{20} eV



$$Q^2 \approx -\delta(E_h^2 - E_0^2)$$

$\Gamma(p \to h + X) > 10^{-10} eV$ ⇨ Decays in few km

$$\delta = (m_h/E_0)^2 < 10^{-18}$$

Superluminal Higgs

$(\,\delta < 0\,)$

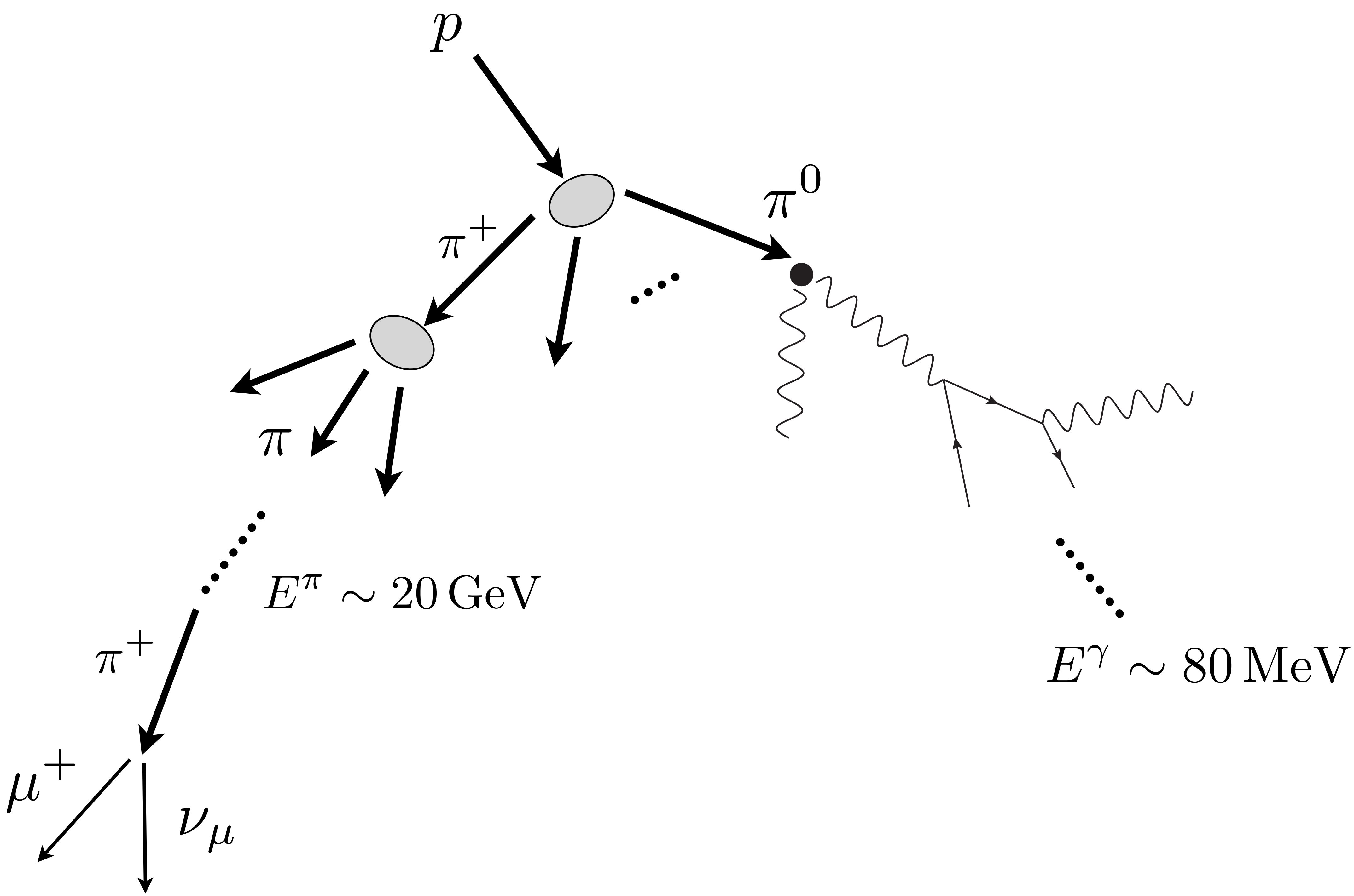
Modified W propagator:

$$D^{\mu\nu} = \frac{-i}{k^2 - M^2}\left[g^{\mu\nu} - \frac{k^\mu k^\nu}{M^2} + \frac{\delta M^2}{k^2 - M^2 + \delta(k\cdot n)^2}\,(\,n^\mu n^\nu + \ldots)\right]$$

Changes Weak Decays

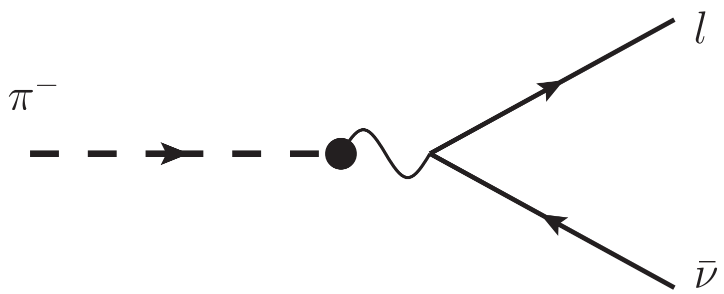
$$J^\mu J_\mu \to J^\mu J_\mu + \left(\frac{M^2}{(k^0)^2 + \underbrace{M^2/(-\delta)}_{E_1^2}}\right) J^0 J^0$$

Extensive Air Showers

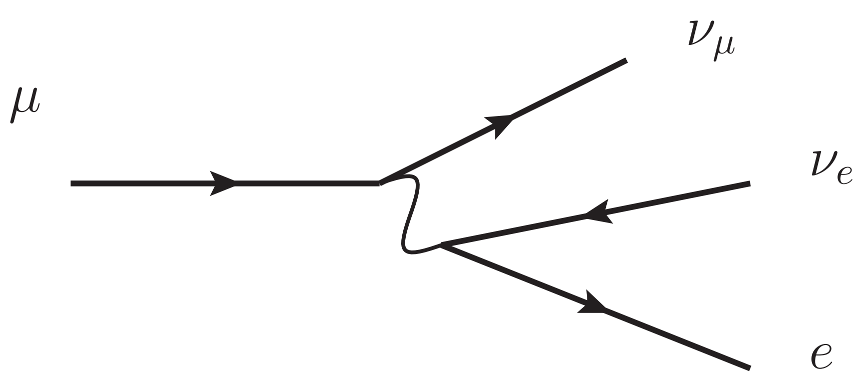


~ 10^{10} particles

Huge changes with LV



$$\Gamma \approx \frac{f_\pi^2 G_F^2 M_W^4}{6\pi E_\pi} \left(\frac{E_\pi^2}{E_\pi^2 + E_1^2} \right)^2$$



$$\Gamma \approx \frac{m_\mu^2 M_W^4 G_F^2}{480\pi^3 E} \left(\frac{E}{E_1} \right)^4 F(E/E_1)$$

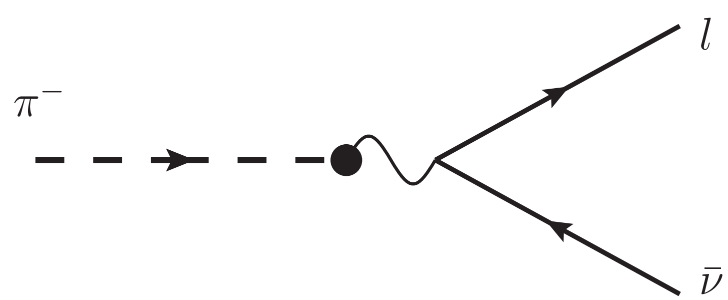
Reminder: $E_1 = M_W / \sqrt{|\delta|}$

Consider, for example: $E_1 \approx 10^{18}\,\mathrm{eV}$ $(|\delta| \approx 10^{-14})$

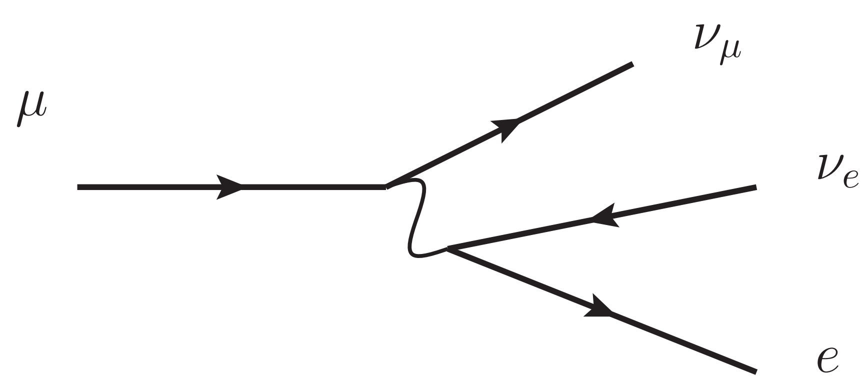
p $\rightarrow$ $\sim 10^2$ π

$10^{20}\,\mathrm{eV}$

$10^{17} - 10^{18}\,\mathrm{eV}$



decays in few meters



decays in few kilometers

Constraints on LV

$\Rightarrow |\delta| \sim 10^{-14}$ leads to huge changes in cosmic ray shower morphology

- No hadronic shower.
- No muons at ground level.

Constrains Lorentz violations in the superluminal case to

$$|\delta| < 10^{-14}$$

Conclusions

- Ultra High Energy Cosmic Rays offer a great opportunity to study Lorentz Violations, even in the Higgs sector.

- Constrains are of the order 10^{-18} for the subluminal Higgs scenario and 10^{-14} for the superluminal case

Thanks!