Chiral Effective Field Theory in QCD

-:Jonathan Hall:-

1. Introducing Lattice QCD

- *Quantum Chromodynamics (QCD)* is a theory which describes the interactions between the constituent particles of nuclei and mesons: *quarks*.

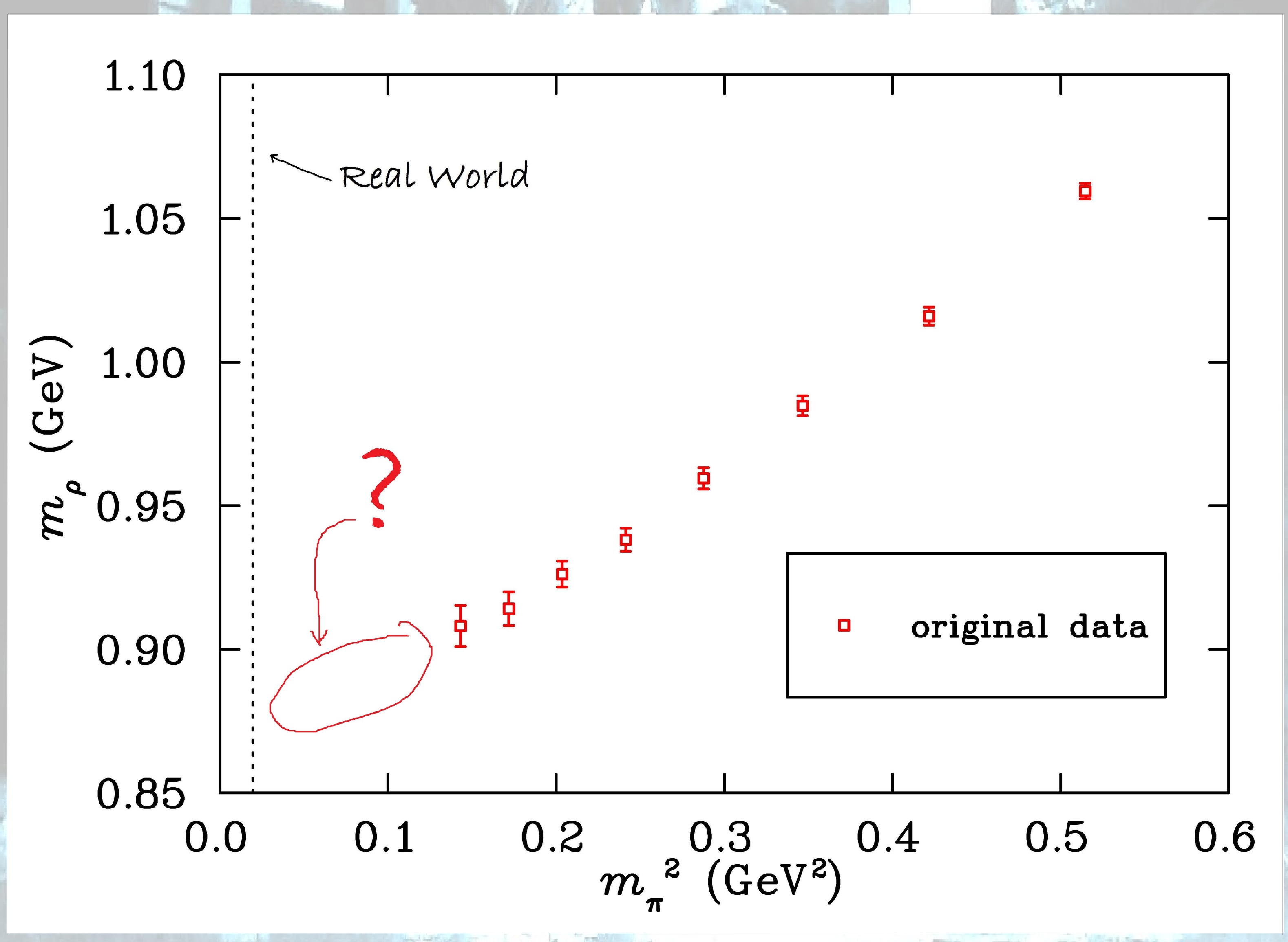
- Quarks interact via gauge fields called *gluons*, and the kinds of subatomic processes that can occur are very hard to calculate.

- *Lattice QCD* is an *ab initio* method for simulating difficult QCD problems on supercomputers, using a box of discrete momenta values.

- Although Lattice QCD is very successful, the computational intensiveness means that calculations are *limited* to *heavy quark masses* or *small box sizes*.

- This leads to *systematic errors* in results, such as finite-volume effects.

"Aim: Use χEFT to predict the physical mass of the quenched ρ meson"



Precision quenched ρ meson mass Lattice QCD data ↲ from Kentucky Group, omitted low energy region shown

2. Enter... Effective Field Theory

- *Chiral Effective Field Theory (χEFT)* is a scheme which only describes the interactions between large particles (such as protons and quenched ρ mesons) at *low energy*.

- We can use χEFT in conjunction with Lattice QCD to *access* the *light quark mass / low energy* behaviour, and calculate an observable quantity such as a particle's *physical mass*.

- χEFT predicts a formula for the quenched ρ meson's mass (in terms of quark mass $m_q \propto m_\pi^2$):

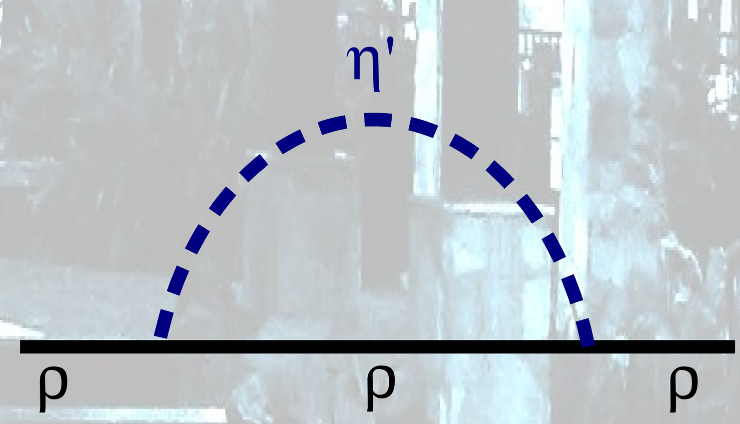
$$m_\rho^2 = \{a_0 + a_2 m_\pi^2 + a_4 m_\pi^4 + \cdots\} + \Sigma_{\eta'} + \Sigma_{\eta'\eta'}$$
$$= c_0 + \chi_1 m_\pi + c_2 m_\pi^2 + \chi_3 m_\pi^3 + c_4 m_\pi^4 + \cdots$$

- The *non-analytic* terms (with known χ-coefficients) are obtained from the (Σ) *integrals*.

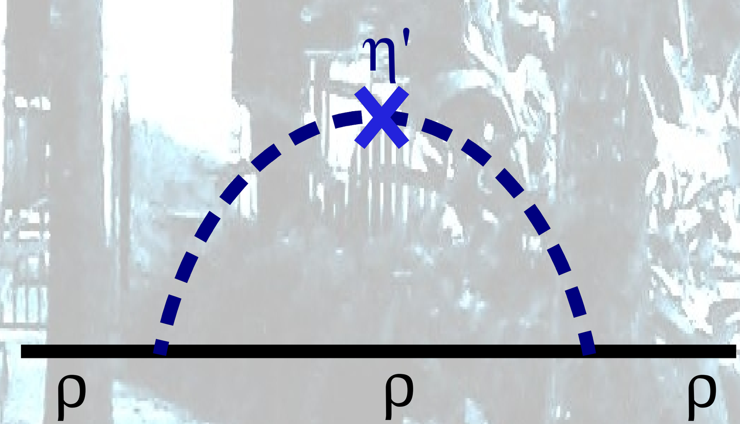
3. Meson Cloud Diagrams

- The quenched ρ meson is surrounded by a cloud of other particles which *contribute to its mass*.

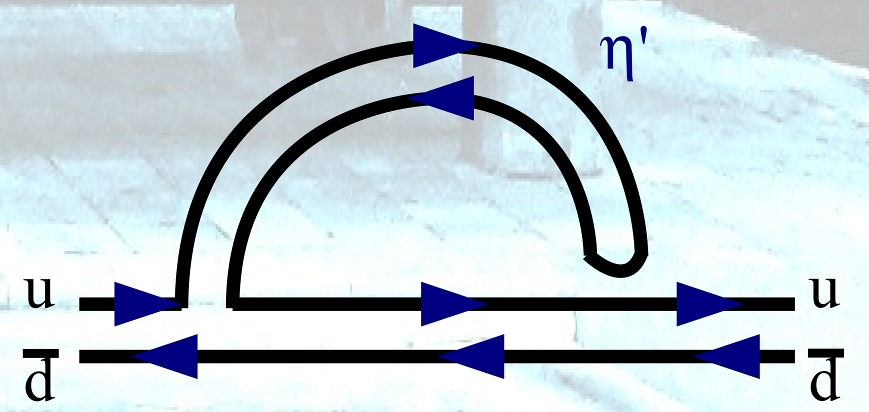
- The most important contributions are the *single* and *double hairpin η' graphs*, which correspond to *integrals*:



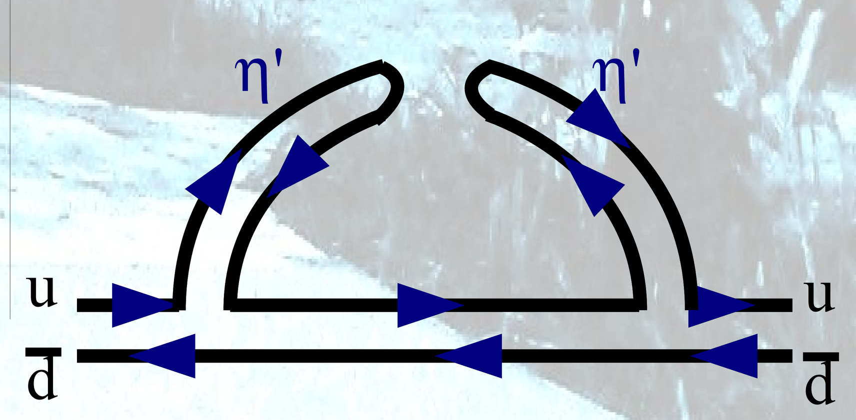
Single hairpin η' diagram ↲



Double hairpin η' diagram ↲



Example single hairpin quark-flow ↲



Example double hairpin quark-flow ↲

$$\Sigma_{\eta'}(m_\pi;\Lambda) = \chi_3 \frac{2}{\pi}\int_0^\infty \mathrm{d}k\, \frac{k^4 u^2(k^2)}{k^2 + m_\pi^2}\ ,\quad \Sigma_{\eta'\eta'}(m_\pi;\Lambda) = \chi_1 \frac{-4}{3\pi}\int_0^\infty \mathrm{d}k\, \frac{k^4 u^2(k^2)}{(k^2 + m_\pi^2)^2}$$

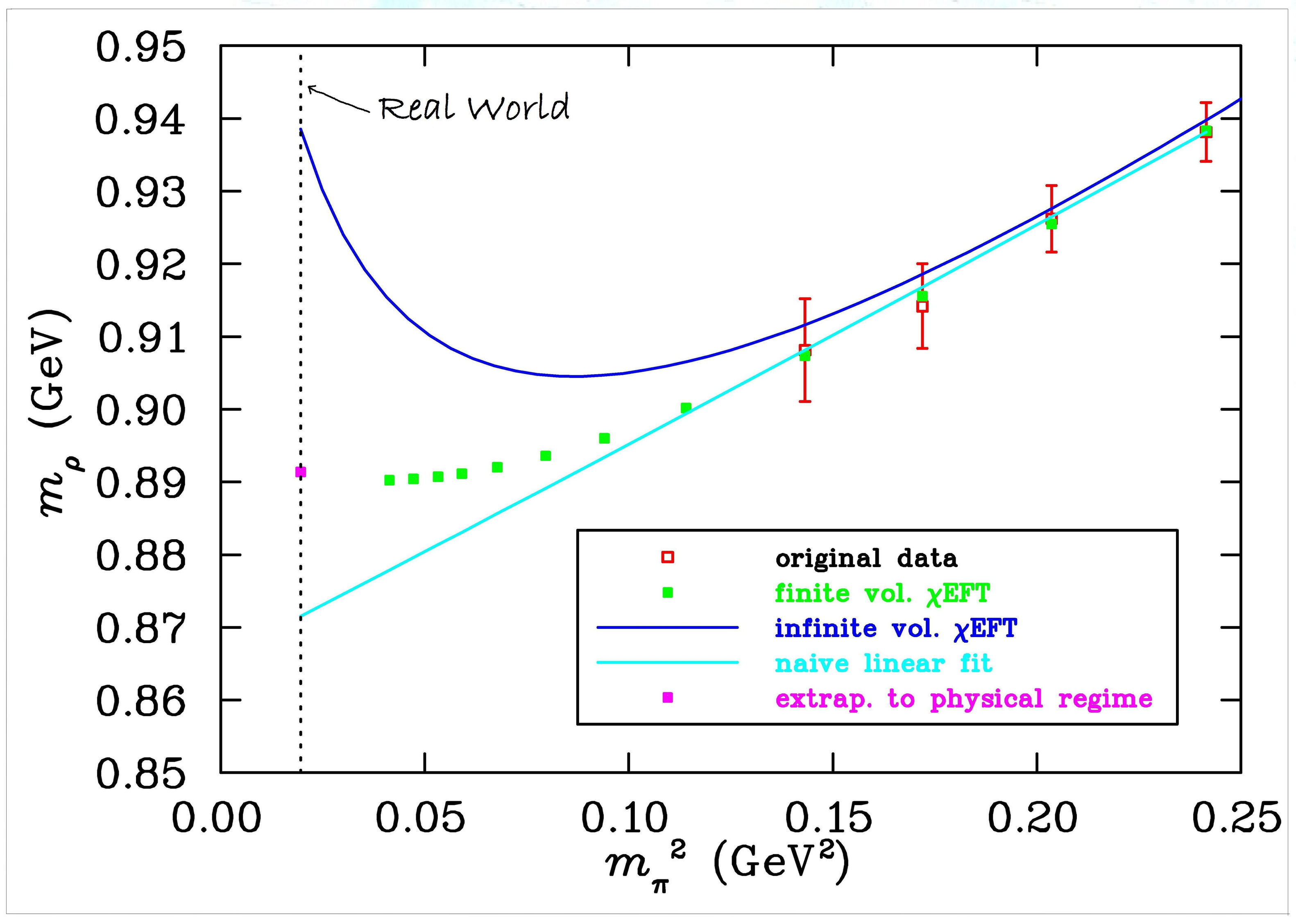
4. Regularisation

- Quantum Field Theory integrals are often *divergent* and *renormalisation* is required.

- Therefore, a *cutoff function* $u(k^2)$ is introduced to regulate the U.V. energy region.

- We use *Finite-Range Regularisation*, with convergence properties superior to standard techniques.

"Missing data points in the low energy region can be obtained from χEFT"



The lightest four data points extrapolated to the 'Real World' ↲

5. Conclusion

- The result obtained from χEFT differs from the naïve fit *non-trivially*.

- The χEFT result can also be corrected for an *infinite volume* lattice box.

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