

# THE MAGNETIC MOMENT OF THE NUCLEON

## CHIRAL EFFECTIVE FIELD THEORY

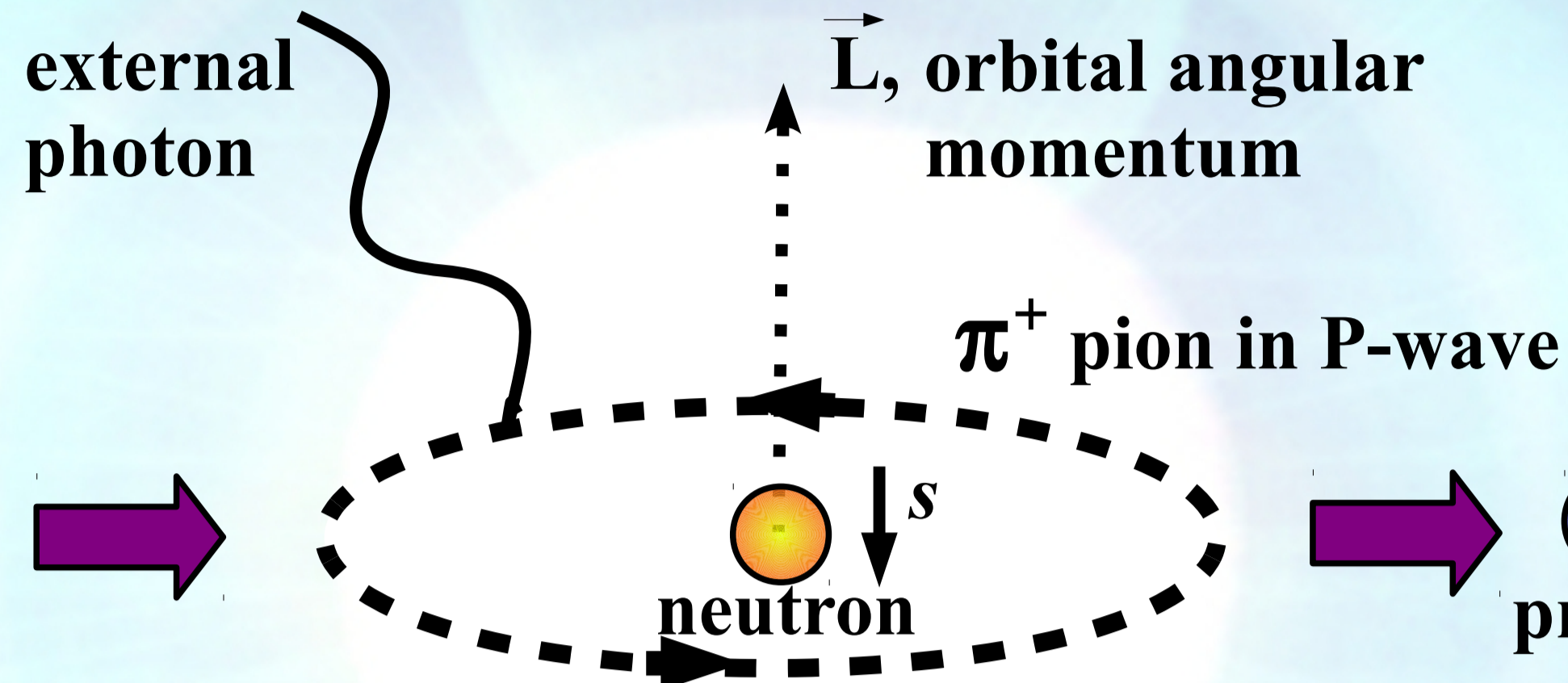
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Is QCD Wrong ??

-What's happened? The graph below shows that **magnetic moment** results from Lattice Quantum Chromodynamics (QCD) do not match the experimental value!

-Is QCD missing something?

-Chiral Effective Field Theory can be used to explore this discrepancy, and confront **theory with experiment!**

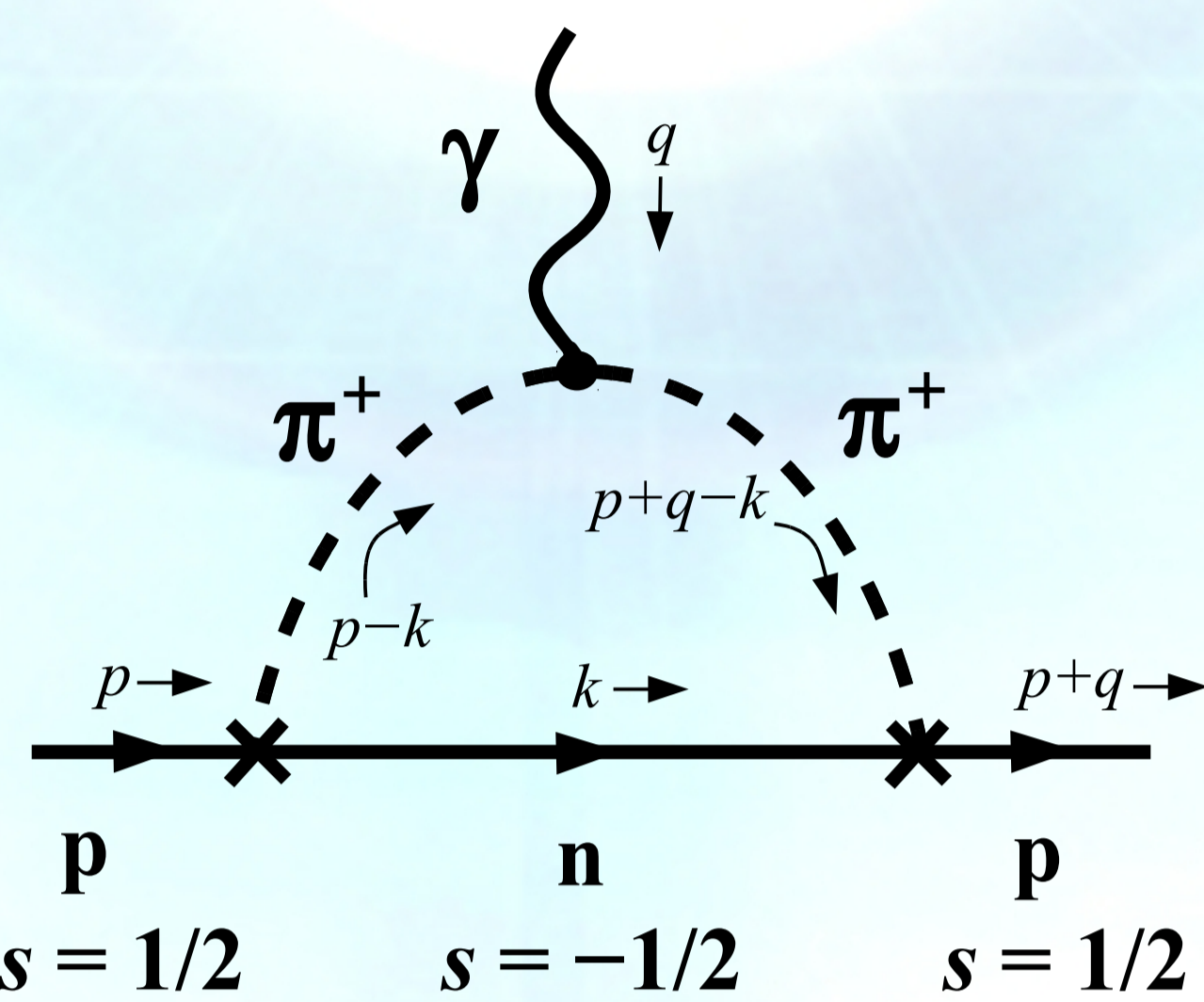


What are Magnetic Moments?

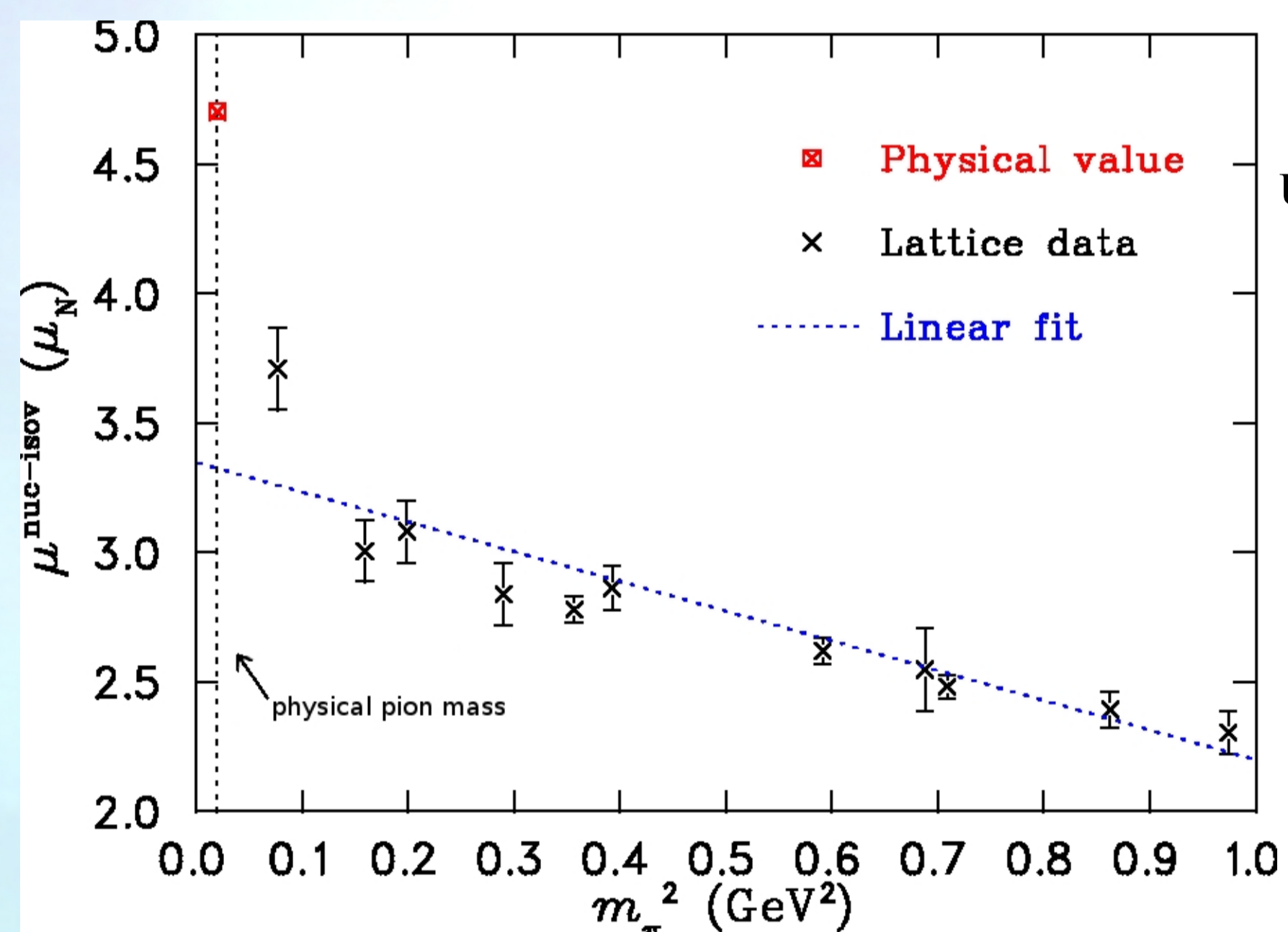
-The **Magnetic Moment** is a measure of the distribution of **spin** and **orbital angular momentum**.

-The **Internal Structure** of a nucleon gives rise to **anomalous corrections** to its Dirac magnetic moment.

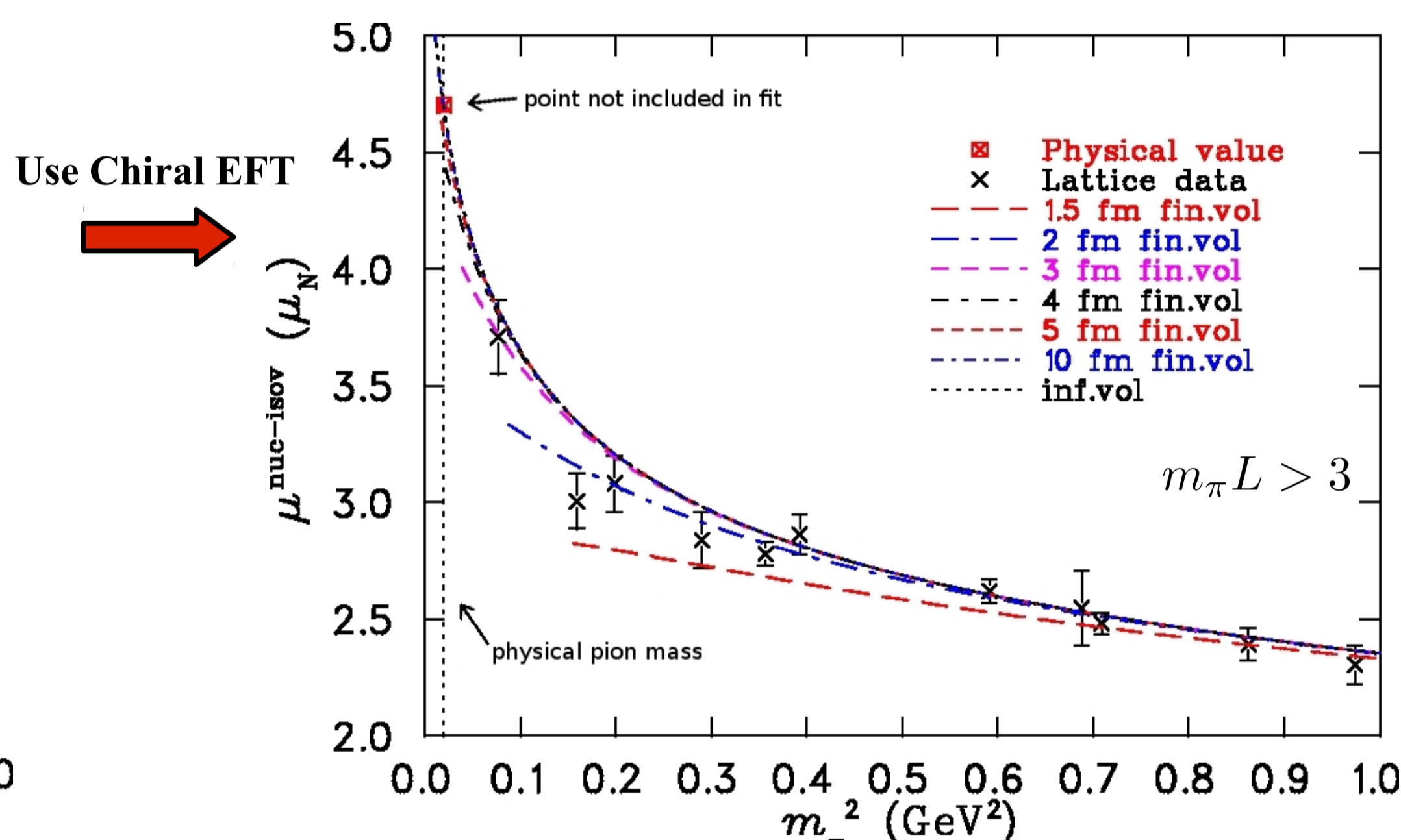
-The **Pion Cloud**, pictured to the left for the proton, is an integral part of its detailed structure, contributing orbital angular momentum.



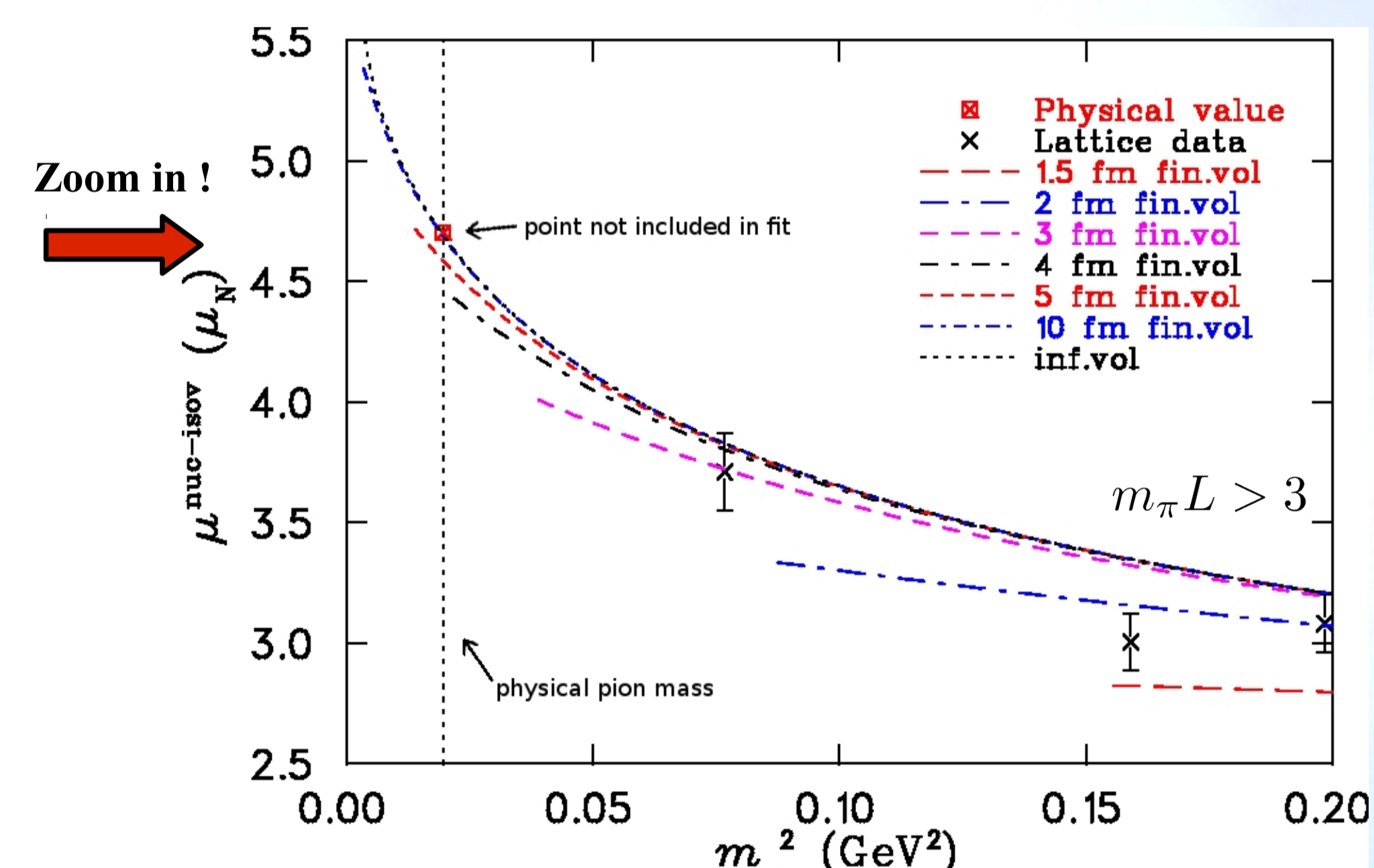
Example: dominant Clebsch-Gordan state for the proton.



**Isovector magnetic moment:** experimental value (red) and lattice results (black) for various quark masses ( $\propto m_\pi^2$ ).

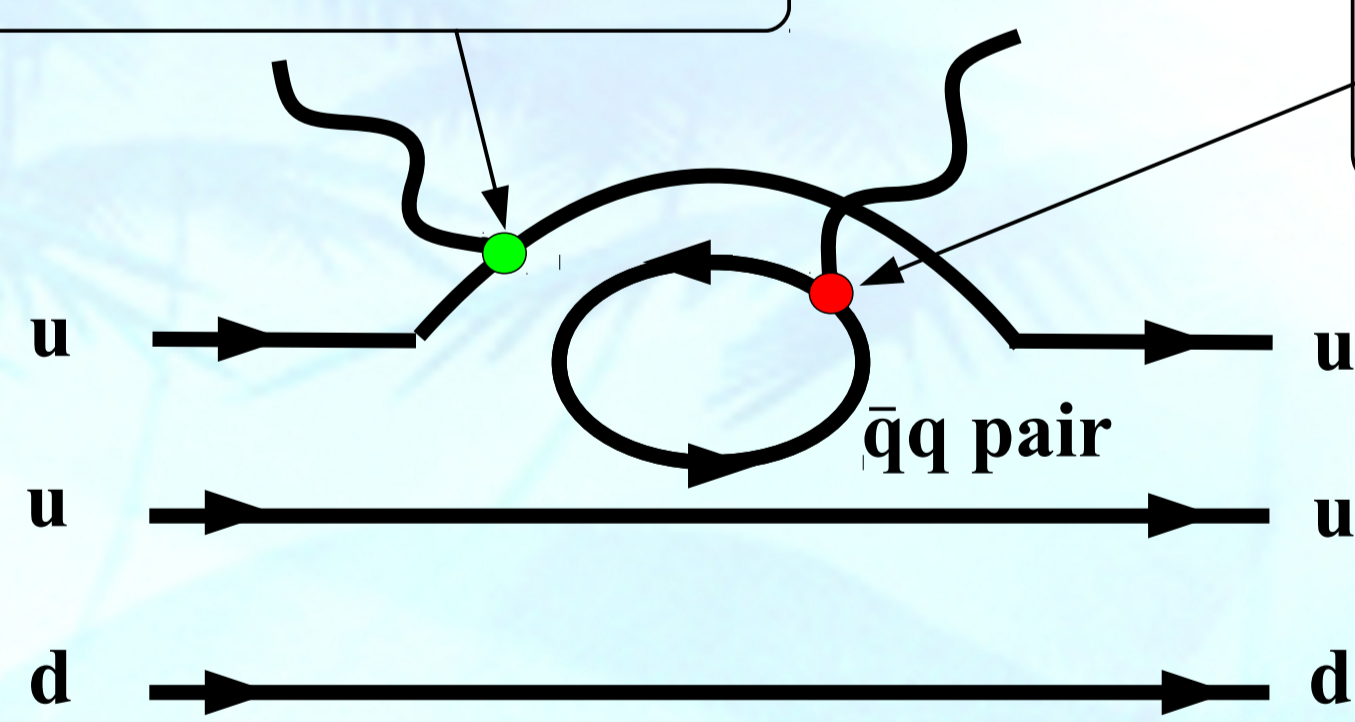


**Chiral Effective Field Theory corrections show large positive chiral curvature** for large lattice sizes.



This large curvature comes from **pion loops** which contribute to the total magnetic moment.

'Direct' quark-photon coupling.



'Indirect' quark-photon coupling: often omitted in Lattice QCD!

Example quark flow: difference between 'direct' and 'indirect' photon couplings.

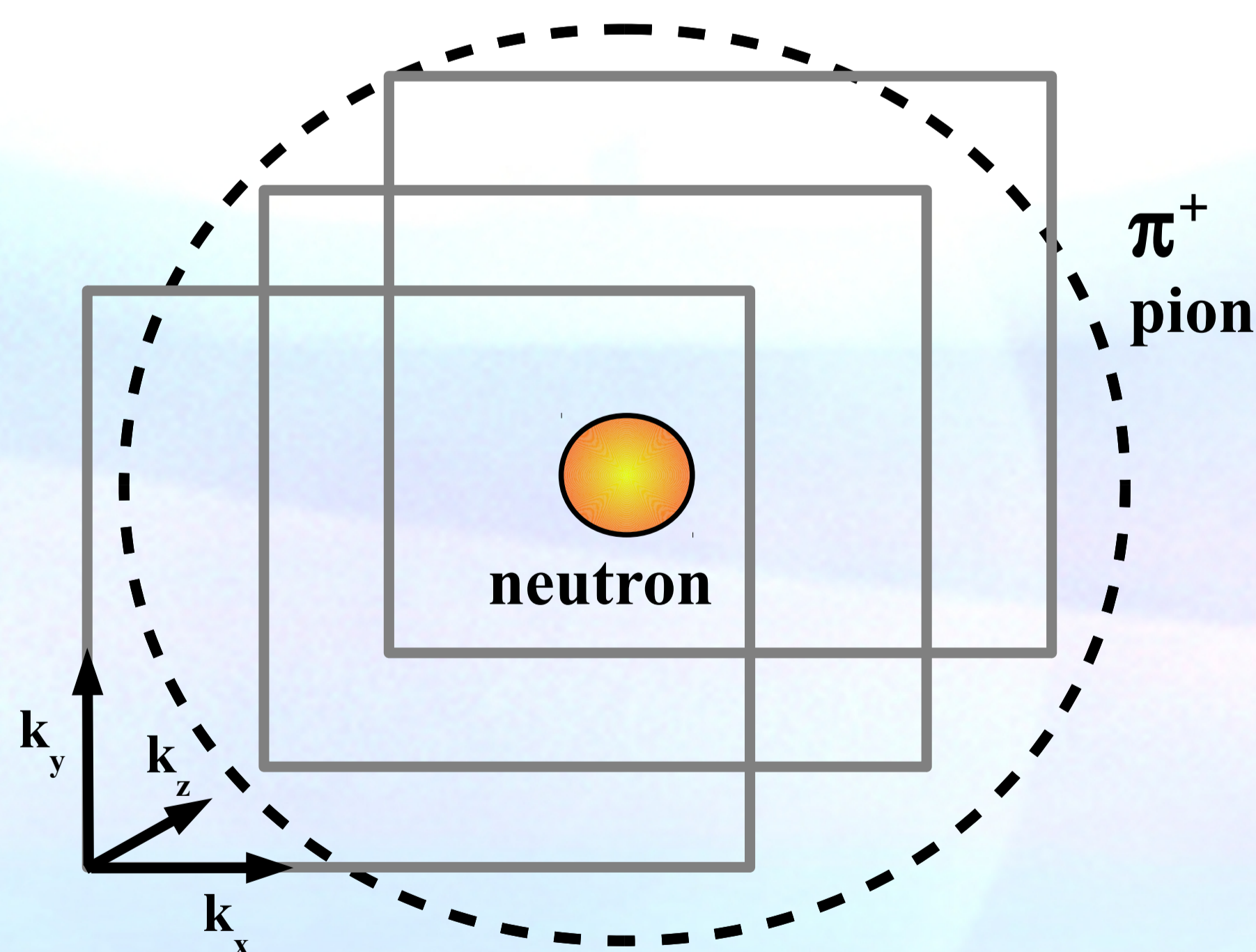
## Chiral Effective Field Theory

-Chiral Effective Field Theory ( $\chi$ EFT) is a low energy theory complementary to Lattice QCD.

-It can be used to overcome difficulties in Lattice QCD. The main issues are:

- Finite volume effects
- Unrealistically large pion masses

-The **isovector** (proton minus neutron) avoids the hard-to-calculate indirect couplings.



-Finite Volume Conundrum:

- finite box size will **deform** the **long-range tail** of the pion cloud.
- The finite volume **discretises the momenta** available on the lattice.

New Results !

-New Results show that the size of the **finite volume corrections** are **significant** for standard  $(3 \text{ fm})^3$  boxes. The magnetic moment differs by  $\sim 12\%$ .

-Very large volumes of  $(5 \text{ fm})^3$  are required to access the physical point with systematic errors of  $\sim 2\%$ .

-We have shown that **low energy QCD** is not wrong after all!  $\chi$ EFT **resolves** the discrepancy by providing **significant curvature** at light pion masses.

- Future Directions include:
- Investigating the **electric charge radius** of the nucleon.
  - Investigating  $\chi$ EFT for less understood observables, such as **nucleon resonances**.