High Energy Theory Group @ NTNU-Physics

Exploring the Origin of Mass with High-Performance Computing

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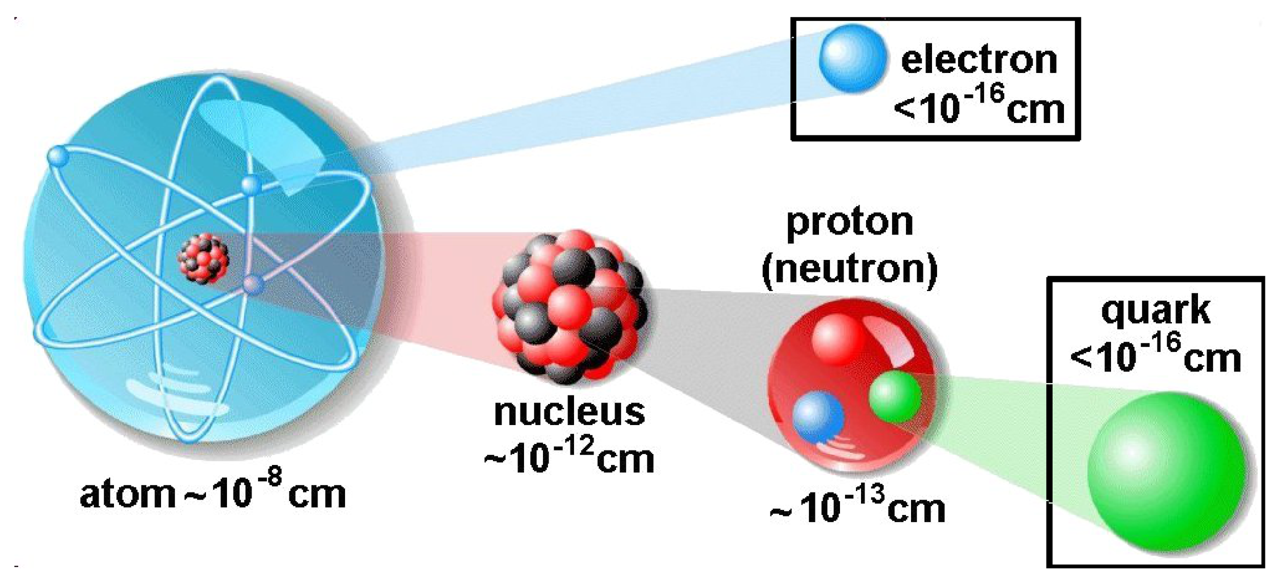
Abstract: Strongly-interacting quantum field theories can explain the origin of mass. High-performance computing is the most reliable method to study such theories, and demands the application of advanced numerical techniques.

Context: The Mystery of Mass



Problem: Elementary particle masses appear to violate a fundamental symmetry of nature

Solution: This electroweak symmetry can be hidden (the "**Higgs mechanism**", Nobel Prize 1979)

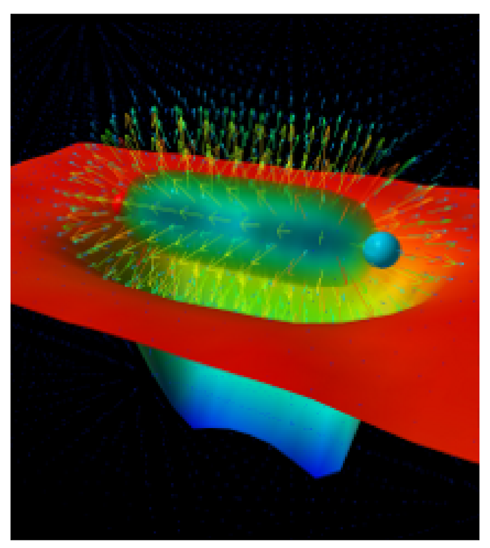
Mystery: There are many possible ways to hide the symmetry

The Large Hadron Collider is searching for evidence that might tell us which possibility is realized in nature

Our focus: new strong dynamics ("technicolor")

Strong interactions

- Example: the **strong nuclear force** binding quarks into protons (etc.)
- Separating two quarks by 10^{-15} meter requires roughly **10 tons** of force
- That's **strong**, but not strong enough to explain elementary particle masses

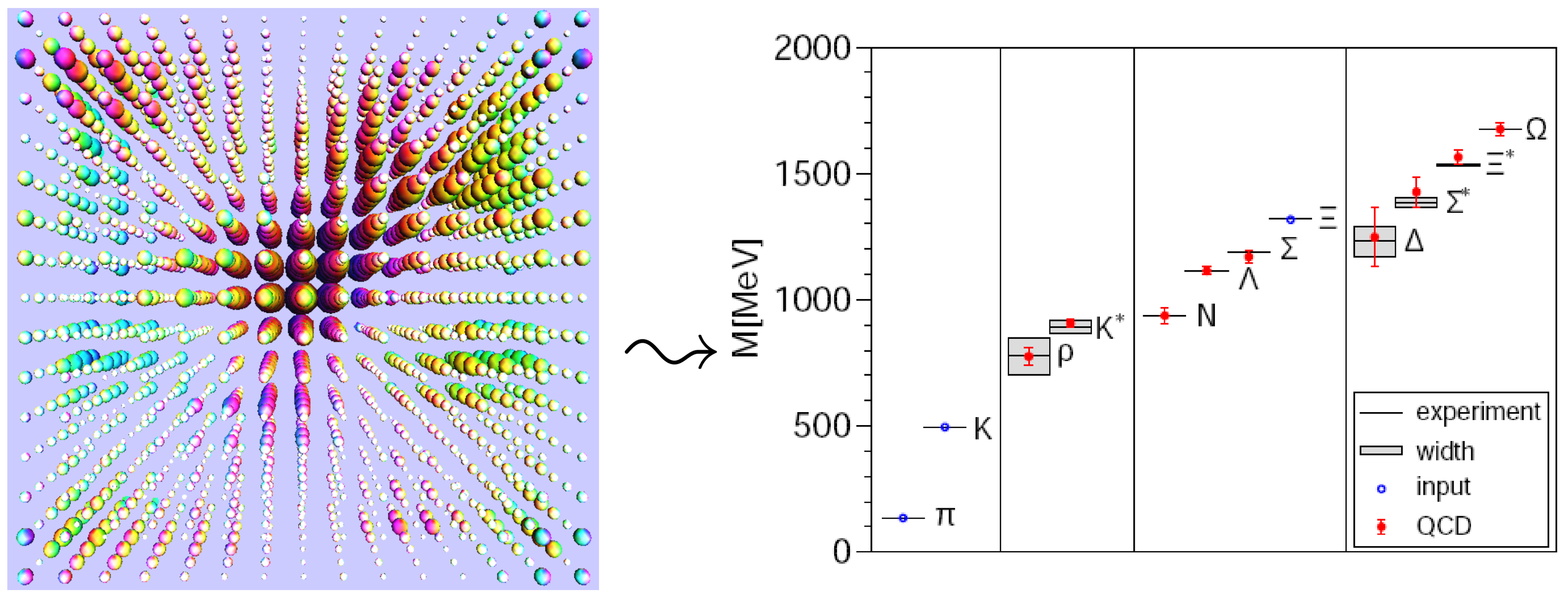


We need to hypothesize a **new, strongly-interacting force**
This is **theoretically elegant** but **analytically intractable**

The trouble with strong interactions:

- Analytic calculations treat interactions as small corrections (**perturbations**) to simpler systems
- Only possible if the interactions are weak in strength

High-performance computing



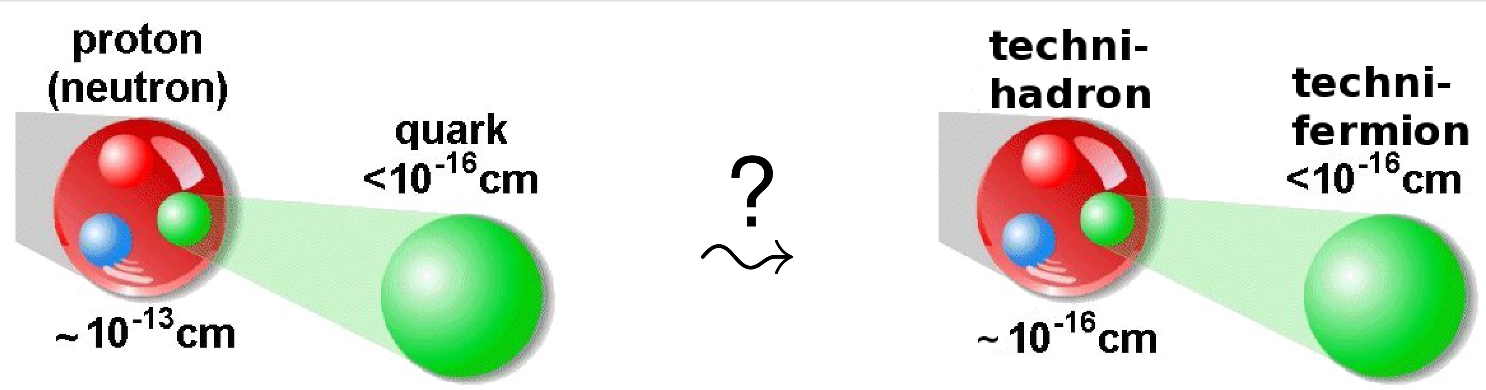
- Replace space and time with a lattice of discrete sites
- As the distance between the sites decreases, recover the original theory in continuum spacetime
- **Lattice field theory** directly investigates strong interactions, but pushes the limits of high-performance computing

New strong dynamics on the lattice

- Lattice studies of the strong nuclear force are a mature field
- Exploration of new strong dynamics is a new frontier

Goal: explore differences from the strong nuclear force

Lacking analytic predictions, the strong nuclear force has often been used to model new strong dynamics



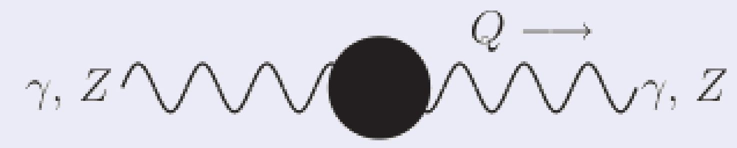
A crucial question that the lattice can address:
Where and how does this approach break down?

Acknowledgments

National Science Council

Example: The S parameter

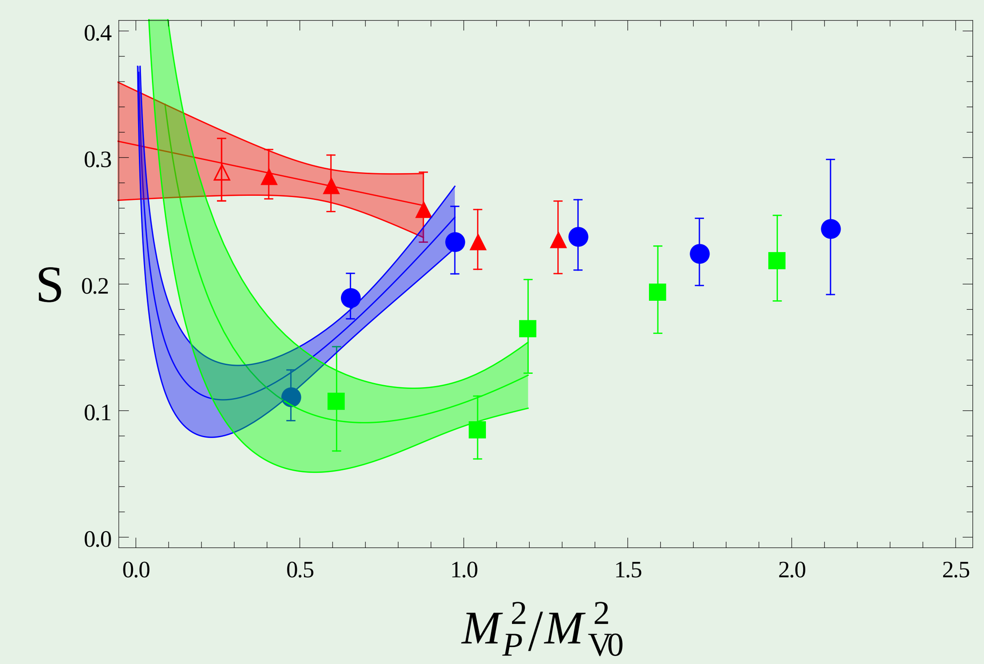
S is an important clue to the Higgs mechanism "whodunit"



It measures the effects of the symmetry-hiding mechanism on the behavior of the Z boson and photon γ

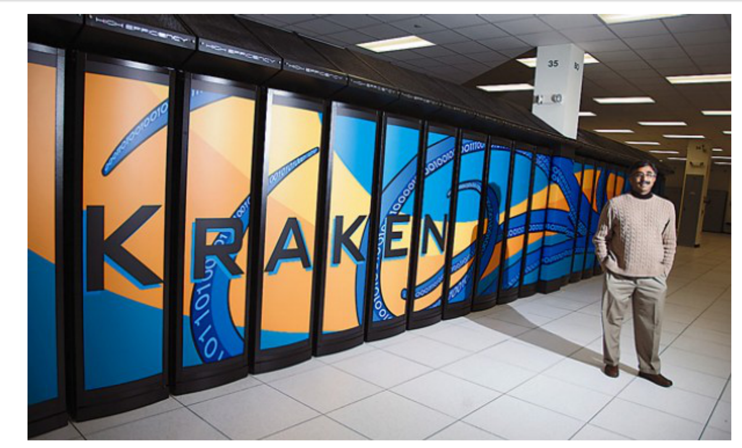
Experiment: $S = -0.15 \pm 0.10$

Lattice: S (blue, green) closer to experiment than expectations based on the strong nuclear force (red)

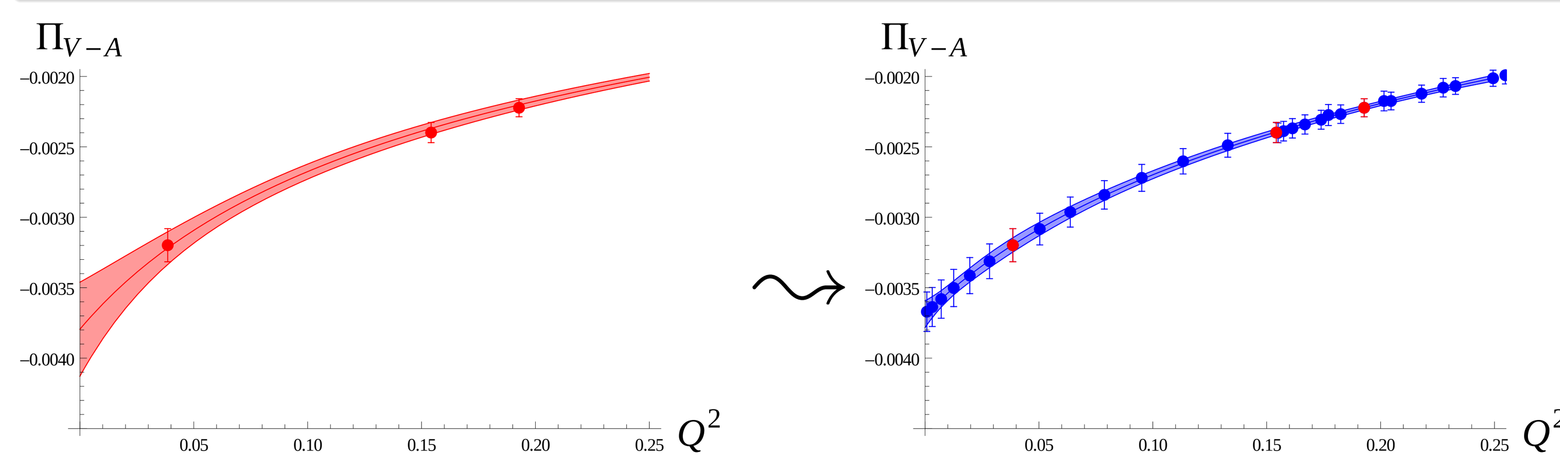


Advanced numerical techniques

These projects require **100s of millions** of core-hours on some of the world's largest supercomputers



Twisted boundary conditions are a novel technique to **efficiently** improve calculations such as the S parameter



S depends on the slope of Π_{V-A} at $Q^2 = 0$