Strongly coupled physics beyond the Standard Model with Peta-scale computing

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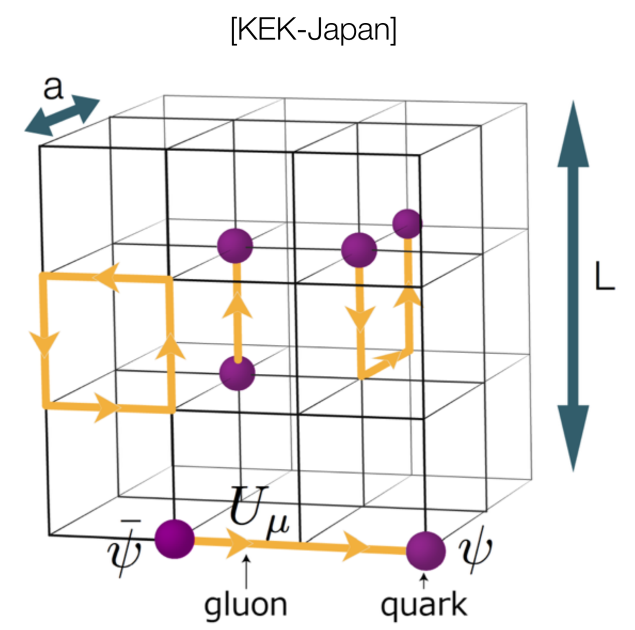
Composite Higgs and more

One of the open questions in theoretical physics is the real origin of mass, which is related to electroweak symmetry breaking and the Higgs mechanism.
The electroweak symmetry could be broken dynamically by a mechanism that requires new strongly coupled physics at high energies - the motivation for this is mainly to explain the hierarchy problem.
In such a framework, the Higgs boson appears as a composite bound state of novel fermions in a new non-Abelian gauge theory.
Given the strong dynamics of the new interactions, non-perturbative calculations are needed to understand the general properties and specific features of the different competing models from the theoretical point of view.

Lattice Gauge Theory simulations

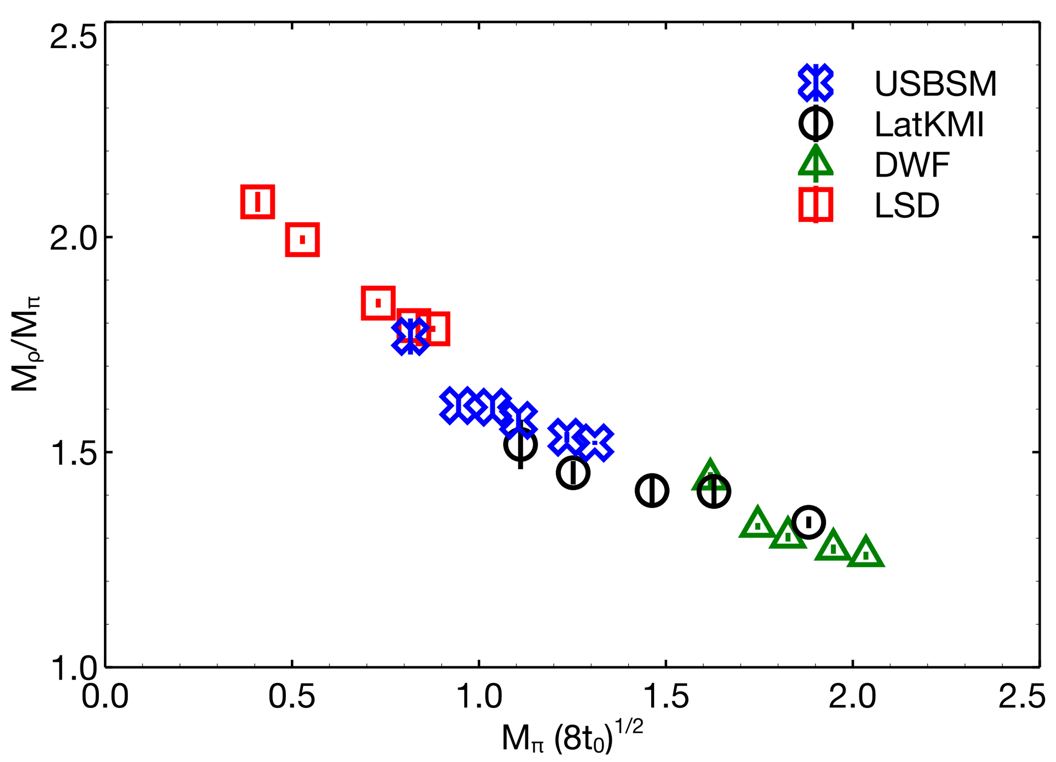


Non-perturbative dynamics arising in non-Abelian gauge theories can be solved with accuracy by discretizing space-time on a lattice and by performing path-integral calculations using Monte Carlo methods of importance sampling.
A theory of new "quarks" and "gluons" can be studied with the same methods used in Lattice QCD.
The main advantages of using these methods are:

- ★ no approximations: the full UV theory is studied from first principles
- ★ improvable statistical and systematic errors: just use a bigger computer
- ★ naive dimensional analysis arguments can be replaced by robust numerical results
- ★ LEC of a given low-energy EFT can be computed for several UV theories
- ★ confronting experiments with trustworthy numbers rather than "order of magnitudes"

A "blueprint" theory of new strong dynamics

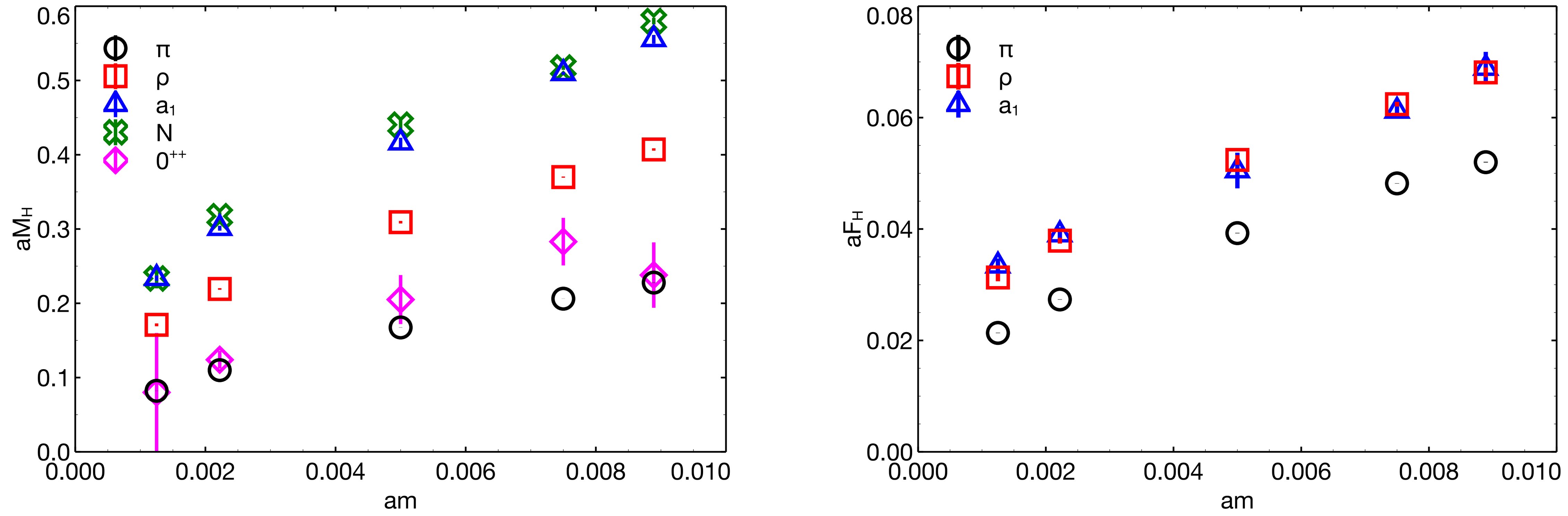
We present results for the spectrum of a strongly interacting SU(3) gauge theory with 8 light fermions in the fundamental representation.
This new sector is used as a representative of UV theories with strong dynamics near the conformal window which are used in the framework of Walking Technicolor to explain the Higgs as a composite particle.
The masses of mesons and baryons in this theory can not be predicted with precision unless the full non-perturbative dynamics is taken into account - a situation very familiar from QCD.



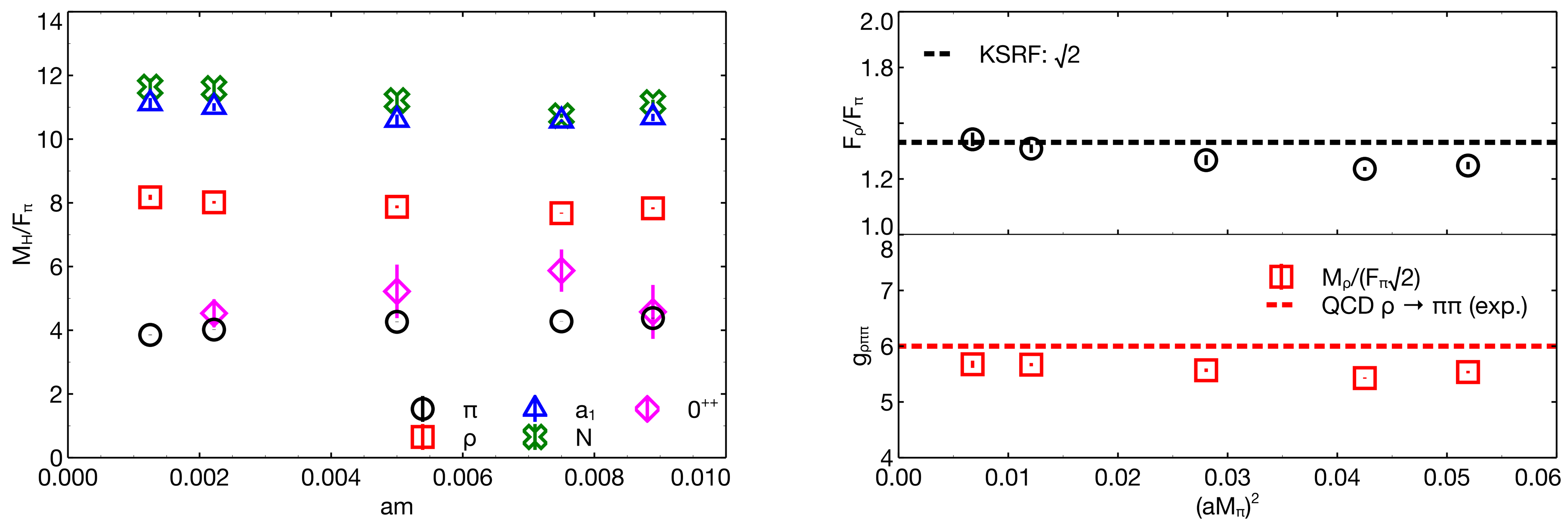
We carry out non-perturbative lattice calculations at the lightest fermion masses and largest box volumes considered to date.
As a proxy for the new "quark" mass we look at the ratio of the lightest vector meson (ρ) to the lightest pseudoscalar meson (π).
Toward the zero mass limit, the ratio M_ρ/M_π increases as in QCD - π is behaving similarly to a pNG boson.

[USBSM - arxiv:1310.7006] [DWF - arxiv:1405.4752]
[LatKMI - arxiv:1302.6859] [LSD - arxiv:1601.04027]

Non-perturbative spectrum - differences and similarities with QCD



The masses M_H and the decay constants F_H of the lowest lying states in the spectrum are accurately measured as a function of the input new "quark" mass (m). The relevant region for composite Higgs models is the limit where this mass goes to zero.
A striking feature of this particular "blueprint" model is an iso-singlet scalar meson with 0^{++} quantum numbers that is degenerate with the pseudoscalar and half the mass of the vector meson - this is unlike QCD where the lightest state of this kind is the $f_0(500)$.



We can estimate the width of the ρ meson using KSRF relations, which we numerically prove to be valid within 10%.
Connecting our results to models of dynamical electroweak symmetry breaking where F_π=246 GeV, we estimate the vector resonance mass to be about 2 TeV with a width of roughly 450 GeV - $\Gamma_\rho/M_\rho \approx 0.22$ - and predict additional resonances with masses below ~3 TeV.

Conclusions

In the context of the search for new physics beyond the Standard Model at the LHC, it is important to now the rich spectrum of resonances of strongly interacting theories: the exact hierarchy of these new bound states would be unknown if it weren't for lattice numerical simulations.
Similarly, decay widths can be calculated with accuracy beyond naive dimensional analysis.
Theories with strong dynamics and a different number of colors and fermions can be easily studied with lattice methods on large supercomputers.

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