From the strong coupling to resonances using lattice QCD.

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Plan of talk

- A lattice QCD calculation of the strong coupling α_s.
- ρ meson chiral extrapolation, leptonic decays.
- ω - ρ [1] mass splitting and mixing.

On this lattice QCD business.

- Karl discussed some of the issues with lattice QCD yesterday, so I am not going to repeat that.
- I am going to report masses and decay constants from lattice QCD with non-zero lattice spacing, volume and sea quarks that are too heavy.

[1] sorry these are the only resonances in the talk

Collaborators

- ETM Collaboration: K. Jansen, C. Michael, C. Urbach.
- HPQCD collaboration: I. Allison, E. Dalgic, C.T.H. Davies, E. Follana, R.R. Horgan, K. Hornbostel, I.D. Kendall, G.P. Lepage, C. McNeile, J. Shigemitsu, H. Trottier, R.M. Woloshyn, K.G. Chetyrkin, J.H. Kuhn, M. Steinhauser, C. Sturm, (arXiv:0805.2999,arXiv:0807.1687)

The projects with the HPQCD collaboration used improved staggered fermions and the calculation with ETMC used the twisted mass formalism.

Figure: Picture of Argonne supercomputer, used for work with HPQCD collaboration.

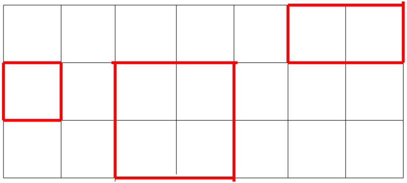
The QCD coupling α_s

The PDG says to compute α_s you need a physical quantity σ with a perturbative expansion

$$\sigma = A_1 \alpha_s + A_2 \alpha_s^2 + \ldots$$

Also need the energy of the coupling. The coupling can be evolved to other scales

$$\mu \frac{\partial \alpha_s}{\partial \mu} = -\beta_0 \frac{\alpha_s^2}{2\pi} - \beta_1 \frac{\alpha_s^3}{4\pi^2} - \beta_2 \frac{\alpha_s^4}{64\pi^3} - \ldots .$$



Calculation of α_s from lattice QCD (arXiv:0807.1687)

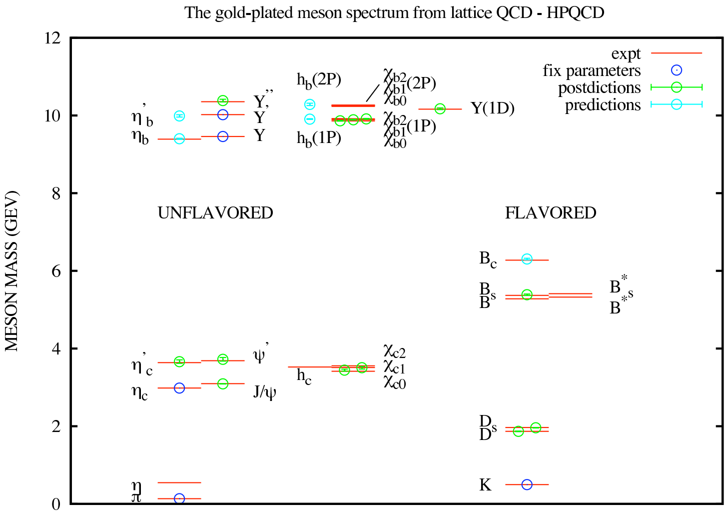
Wilson loops from numerical lattice QCD and perturbation theory.

$$\langle W \rangle = \sum_{n=1}^{10} c_n \alpha_s^n + O(\alpha_s^{11})$$

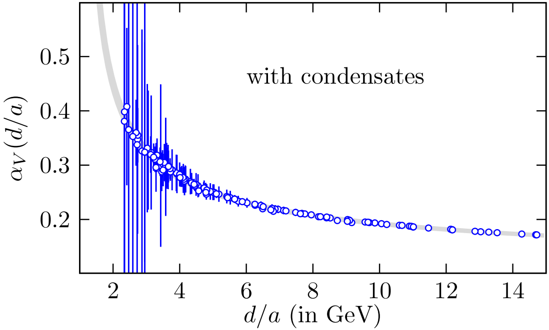
The coupling is at the scale d/a where a is the lattice spacing and d is set from Brodsky-Lepage-Mackenzie scale setting.

- Used unquenched QCD gauge configurtions, generated with 2+1 flavours of improved staggered sea quarks, by the MILC collaboration
- The calculation used data at 6 different lattice spacings (0.178 fm to 0.045 fm), 22 different Wilson loops were used at each lattice spacing with different "d" values.
- Lattice spacing from r_1 (physical value of r_1 from Upsilon spectrum).
- The coefficients c_1, c_2, and c_3 have been computed in lattice perturbation theory, and the coefficients c_i (i=4 to 10) are included as Bayesian constraints.

Gold plated hadron spectroscopy (HPQCD collaboration)



Strong coupling at different scales



Evolve α_s up to the mass of the Z boson (91 GeV).

Summary of α_s estimates

Summary of α_s in $\overline{MS}$ scheme

Calculation	Ref.	Method	$\alpha_s(M_Z)$
PDG-2005	PDG	"answer"	0.1176(20)
PDG-2005	PDG	summary-all	0.1176(9)
PDG-2005	PDG	summary nonlatt	0.1185(9)
QCDSF-2005	hep-ph/0502212	latt, Wilson $n_f = 2$	0.112(1)(2)
HPQCD-2005	hep-lat/0503005	stagg lattice	0.1170(12)
Maltman et al.	arXiv:0807.2020	stagg lattice	0.1192(11)
HPQCD-charm	arXiv:0805.2999	stagg, charm, latt	0.1174(12)
HPQCD-2008	arXiv:0807.1687	stagg lattice	0.1183(8)

The HPQCD-2008 result has an error of 0.7 % and the results are moving at the 1 σ level.

Comments on the calculation

- The basic method has been around since early 1990s.
- The update on HPQCD's 2005 result was triggered by the availablity of lattice QCD results at finer lattice spacings (0.06 and 0.045 fm).
- Another analysis by Maltman, Leinweber et al. arXiv:0807.2020 on a subset of the data. Maltman is an expert on extracting α_s from τ decays.

Other lattice results for α_s????

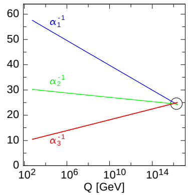
- The QCDSF collaboration use a "similar" method to HPQCD method.
- Elegant method by ALPHA collaboration, not yet produced a precise number for QCD, but being used for α_s with many flavours (walking technicolor).

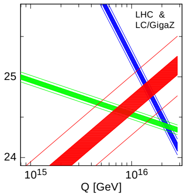
Summary $\alpha_s(M_Z)$ (Maltman et al. arXiv:0807.2020)

Source	$\alpha_s(M_Z)$
Global EW fit	0.1191 ± 0.0027
H1+ZEUS NLO inclusive jets	0.1198 ± 0.0032
H1 high-Q^2 NLO jets	0.1182 ± 0.0045
NNLO LEP event shapes	0.1240 ± 0.0033
NNNLL ALEPH+OPAL thrust distributions	0.1172 ± 0.0022
$\sigma[e^+e^- \to hadrons]$ (2-10.6 GeV)	$0.1190^{+0.0090}_{-0.0110}$
$\frac{\Gamma[\Upsilon(1s)\to\gamma X]}{\Gamma[\Upsilon(1s)\to X]}$	$0.1190^{+0.0060}_{-0.0050}$
hadronic τ decay	0.1187 ± 0.0016
PDG-2005 (summary non-lattice)	0.1185 ± 0.0009
HPQCD-2005	0.1170 ± 0.0012
HPQCD-2008	0.1183 ± 0.0008

How precise do we need α_s ?

- In previous versions of this talk, I motivated the α_s calculation as showing the lattice QCD calculations were consistent with perturbative QCD. However, ..
- TESLA Technical Design Report Part III: Physics at an e+e- Linear Collider, (arXiv:hep-ph/0106315), and hep-ph/0601217 by Zerwas et al.. One goal of the linear collider to determine $\delta\alpha_s(M_z) = 0.001$.
- It is important to experimentally study energy dependence of $\alpha_s(\mu)$.





Unification and α_s (Peskin, hep-ph/9705479)

One loop evolution of QCD and electroweak couplings to common coupling at unification scale M_U

$$\begin{aligned} 1/\alpha_U(M_U) &= 1/\alpha_s(M_Z) + \frac{b_3}{2\pi}\log(M_U/M_Z) \\ 1/\alpha_U(M_U) &= 1/\alpha_2(M_Z) + \frac{b_2}{2\pi}\log(M_U/M_Z) \\ 1/\alpha_U(M_U) &= 1/\alpha_1(M_Z) + \frac{b_1}{2\pi}\log(M_U/M_Z) \end{aligned}$$

$$\alpha_2^{-1} = \alpha_{em}^{-1}\sin^2(\theta_W) \quad , \; \alpha_1^{-1} = \frac{3}{5}\alpha_2^{-1}\cot^2(\theta_W)$$

$$B = \frac{1/\alpha_s(M_Z) - 1/\alpha_2(M_Z)}{1/\alpha_2(M_Z) - 1/\alpha_1(M_Z)} = \frac{b_2 - b_3}{b_1 - b_2}$$

SUSY unification

b_i	Standard model	MSSM
b_3	11 - $\frac{4}{3} n_g$	9 - 2 n_g
b_2	$\frac{22}{3}$ - $\frac{4}{3} n_g$ - $\frac{1}{6} n_h$	6 - 2 n_g - $\frac{1}{2} n_h$
b_1	- $\frac{4}{3} n_g$ - $\frac{1}{10} n_h$	-2 n_g - $\frac{3}{10} n_h$
B(theory)	0.528	0.714

where n_g generations and n_h Higgs doublets.

Source	$\alpha_s(M_Z)$	B_{expt}
PDG	0.1176(20)	0.718(5)
HPQCD	0.1183(8)	0.720(2)

- The error on α_s dominates the experimental determination of B.
- More importantly than moving to higher loop RG is the inclusion of threshold effects. See GUT review in PDG.
- The error $\sin^2(\theta_w)$ is 0.17% and error on HPQCD's α_s of 0.7%.

Hadron Spectroscopy

QCD predicts novel bound states:

- Glueballs are bound states of glue.
- Hybrid mesons, quark and anti-quark and excited glue
- Tetraquark/molecules

Need to first validate lattice techniques with the simpler ρ meson.

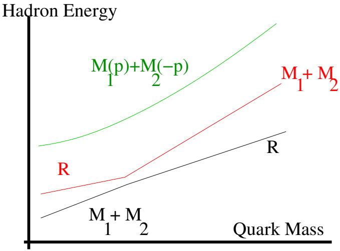
(c) 12 GeV upgrade Jlab

(d) Panda at FAIR

Cartoon of meson decay

Resonance decay $R \longrightarrow M_1 + M_2$

- S-wave decay, decay threshold $M_{DT} = M_1 + M_2$
- P-wave decay, decay threshold $M_{DT} = \sqrt{M_1^2 + p^2} + \sqrt{M_2^2 + p^2}$, p $= \frac{2\pi}{L}$ ($\sim$ 500 MeV)



(Elegant method proposed by Lüscher, Nucl. Phys. B364, 237, 1991. First application for ρ decay , ariv:0708.3705, by CP-PACS.)

Introducing the ρ meson

One version of effective field theory of vector mesons "predicts" a chiral extrapolation model of

$$m_\rho = m_\rho^0 + d_1 m_\pi^2 + d_2 m_\pi^3 + \ldots$$

(from Jenkins, Manohar and Wise. Phys.Rev.Lett 75, 2272 (1995)).

- The large mass of the ρ meson can cause problems with power counting in effective field theory.
- Unlike the π the mass of the ρ is close to other resonances (a_0, b_1, ..), hence we may have problems with the convergence of the effective field theory.
- The ρ meson decays to two π. This is not included in effective field theory because the pions are not soft.
- Experimentally the mass splitting between the ρ^0 and ρ^+ is not resolved. (m_{ρ^+} - $m_{\rho^0} = 0.1 \pm 0.9$ MeV, hep-ph/9901211) (This is an issue for us because we don't include electromagnetism).

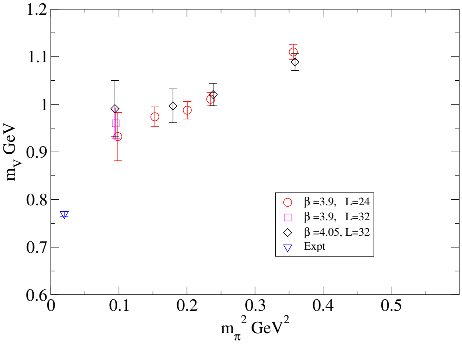
Data sets used for ρ

The following n_f=2 data sets from ETMC used. Recent preprint with moe detail: arXiv:0906.4720.

β	a L	L fm	a^{-1} MeV
3.9	24	2.1	2268
3.9	32	2.8	2268
4.05	32	2.1	2957

- Used stochastic sources ("one end trick") for the quark propagtors to improve the signal to noise ratio.
- Using fits to 4 by 4 correlation matrices (local, fuzzed, and two rho operators) done by Chris Michael.
- Use f_π to set the lattice spacing, consistent with using the mass of the nucleon to set the scale.

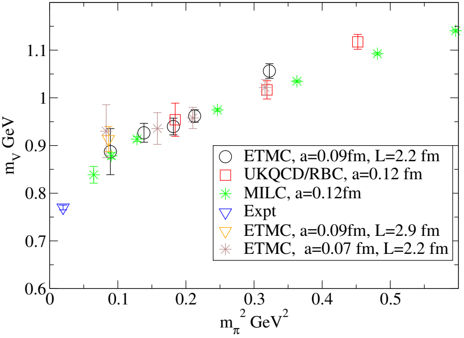
Mass of light vector mesons



Optimistically I hoped that the chiral extrapolations would help.

Comparison of masses of ρ

Comparison of lattice data for the mass of the ρ meson from different lattice formalisms. We have checked that the signal to noise of the correlators goes like $\sim e^{-(m_\rho - m_\pi)t}$ for ETMC results. Also tried "colour dilution", but that didn't reduce the errors.



Chiral extrapolation of the ρ mass

"New" chiral extrapolation formulae for the ρ meson by Bruns and Meißner (hep-ph/0411223). This uses a modified $\overline{MS}$ regulator.

$$M_\rho = M_\rho^0 + c_1 M_\pi^2 + c_2 M_\pi^3 + c_3 M_\pi^4 \ln(\frac{M_\pi^2}{M_\rho^2})$$

Need to check that size of c_i is consistent with other estimates (eg. from $\omega\rho\pi$ coupling), they claim phemenology prefers $\mid c_i \mid < 3$. Leinweber et al. (hep-lat/0104013) claim to know sign and magnitude of c_2.
Too many parameters to determine with this data, so use an augmented χ^2 with the above constraints built in (hep-lat/0110175).

$$\chi^2_{aug} = \chi^2 + \sum_{j=2}^{3} \frac{(c_i - 0)^2}{3^2}$$

This builds in the "physics" constraints into the fit.

Chiral extrapolations

Tried the fit model suggested by the Adelaide group (Leinweber et al. hep-lat/0104013)

$$m_\rho = c_0 + c_2 m_\pi^2 + \frac{\Sigma_{\pi\omega}(\Lambda_{\pi\omega}, m_\pi) + \Sigma_{\pi\pi}(\Lambda_{\pi\pi}, m_\pi)}{2(c_0 + c_2 m_\pi^2)}$$

where $\Sigma_{\pi\omega}$ and $\Sigma_{\pi\pi}(\Lambda_{\pi\pi}, m_\pi)$ are the self energies from the $\pi\pi$ and $\pi\omega$ states.

$$\Sigma_{\pi\pi} = -\frac{f_{\rho\pi\pi}^2}{6\pi^2}\int_0^\infty \frac{dkk^4 u_{\pi\pi}^2(k)}{(\sqrt{k^2+m_\pi^2})(k^2+m_\pi^2-m_{\rho\ phys}^2/4)}$$

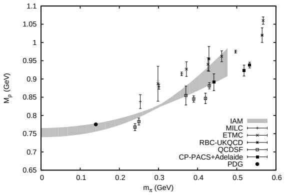
$$\Sigma_{\pi\omega} = -\frac{g_{\rho\omega\pi}^2 m_{\rho\ phys}}{12\pi^2}\int_0^\infty \frac{dkk^4 u_{\pi\omega}^2(k)}{k^2+m_\pi^2}$$

The $u_{\pi\pi}$ and $u_{\pi\omega}$ functions are dipole regulators.

Additional constraints (perhaps)

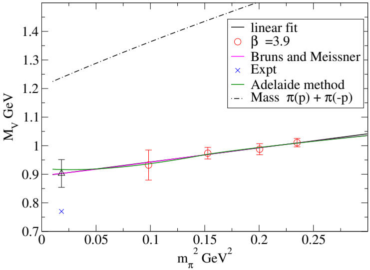
- arXiv:0905.3489, arXiv:0801.2871, Hanhart, Pelaez, and Rios use dispersion relations with chiral perturbation theory (inverse amplitude method).
- $g_{\rho\pi\pi}$ independent of quark mass.

$$m_\rho = (0.735 \pm 0.0017) + (0.90 \pm 0.11 \pm 0.13) m_\pi^2 + O(m_\pi^3)$$



Some results for the chiral extrapolation.

Only fit the $\beta = 3.9$ data.



The linear fit produced $m_\rho = 0.89(5)$ GeV and $c_1 = 0.49(26)$ Gev^{-1}. The fit using the Adelaide fit model produced a $\Lambda_{\pi\omega} = 520$ MeV (a bit low) and was unstable with the bootstrap samples.

Leptonic decay constants

In the continuum the decay constant of the ρ meson is defined via

$$\langle 0 \mid V_\mu \mid \rho \rangle = m_\rho f_\rho \epsilon_\mu$$

where the vector current is defined via

$$V_\mu(x) = \overline{\psi}(x)\gamma_\mu \psi(x)$$

The transverse decay constant ($f_V^T(\mu)$) of the ρ meson is defined by

$$\langle 0 \mid \overline{\psi}\sigma_{\mu\nu}\psi \mid \rho \rangle = i f_V^T(\mu)(p_\mu \epsilon_\nu - p_\nu \epsilon_\mu)$$

where $\sigma_{\mu\nu} = i/2[\gamma_\mu, \gamma_\nu]$. The transverse decay constant is used in light cone sum rule calculations.
Most activity (apart from QCDSF) on weak matrix elements that involve the ρ meson have stopped, because of the problem with the ρ decay. Test lattice techniques on f_ρ and then predict $f_V^T(\mu)$.

Light cone sum rules

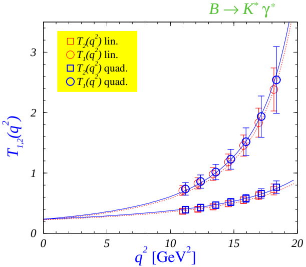
The non-perturbative input to light cone sum rules are the light cone wave functions of mesons (rather than condensates).
Motivation from light cone sum rule for $B \to \rho \ell \nu$, required for $\mid V_{ub} \mid$ from Becirevic et al. (hep-lat/0301020)

$$A_1(q^2) = \frac{m_b f_\rho \mathrm{e}^{(m_B^2 - m_b^2)/M^2}}{m_B^2 f_B (m_B + m_\rho)} \int_{u_0}^{1} \frac{du}{u} \mathrm{e}^{(1-1/u)(q^2 - m_b^2 - u m_\rho^2)/M^2} \times$$
$$\left\{ \frac{m_b^2 + u^2 m_\rho^2 - q^2}{2u} \frac{f_\rho^T}{f_\rho} \phi_T(u) + \frac{m_b m_\rho}{2} \left[\int_0^u dv \frac{\phi_\parallel(v)}{1-v} + \int_u^1 dv \frac{\phi_\parallel(v)}{v} \right] \right\},$$

where M^2 is the Borel parameter.
Changing f_ρ^T / f_ρ from 0.75 to 1 changes $A_1(q^2)$ by up to 20%.
Most lattice groups have stopped work on this decay, preferring to look at $B \to \pi \nu l$ to get $\mid V_{ub} \mid$

More motivation

Ball and Zwicky (hep-ph/0603232) use light cone sum rules and the data from $B \to \rho\gamma$ and $B \to K^\star\gamma$ to extract the CKM matrix elements $| V_{td} | / | V_{ts} |$. This can be compared against the result from B_s mixing. The transverse decay constant of the ρ meson is an important part of their calculation.
Form factor for $B \to K^\star\gamma$ from quenched lattice QCD (hep-ph/0611295, Becirevic et al.)



Renormalisation

The decay constants obtained from the lattice calculation need to be converted to the $\overline{MS}$ scheme.

$$\begin{aligned} \langle i \mid V_\mu^3 \mid j \rangle_{cont} &= Z_V \langle i \mid V_\mu^3 \mid j \rangle_{twisted\ lattice} \\ \langle i \mid T_{\nu\mu}^\alpha \mid j \rangle_{cont} &= Z_T \langle i \mid T_{\nu\mu}^\alpha \mid j \rangle_{twisted\ lattice} \end{aligned}$$

where α takes the values of 1 or 2. Use the results from the Rome-Southampton method and conserved vector current, (slightly updated from those) reported by ETMC in arXiv:0710.0975, Dimopoulos et al.

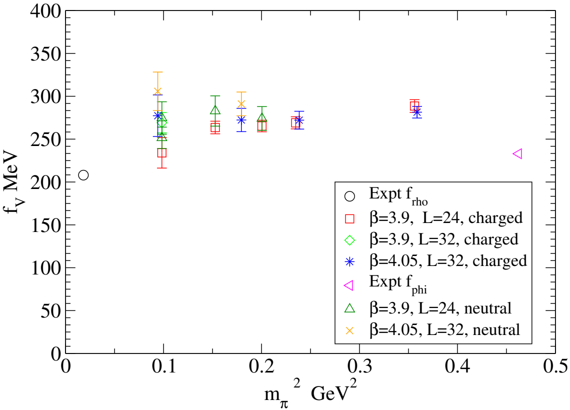
β	Z_A	$Z_T(\mu = \frac{1}{a})$	Z_V
3.9	0.771(4)	0.769(4)	0.6104(02)
4.05	0.785(6)	0.787(7)	0.6451(02)

Chiral extrapolations of ρ decay constants

- There are expressions for quark mass dependence of the vector meson decay constants by Bijnens et al. (hep-ph/9801418). The corrections due loops start at $m_q \log m_q$ and $m_q^{3/2}$ with light quark mass m_q.
- For the f_ρ^T decay constant, chiral perturbation theory for tensor sources has been developed (arXiv:0705.2948, Cata and Mateu) but no loop calculations have been reported.
- Just used linear fits, because of the size of the errorbars.
- Many groups only report f_ρ^T / f_ρ to try and reduce the systematic and statistical errors.
- If we don't separately compute f_ρ we don't have a good test of the calculation.

Results for f_ρ

The leptonic decay constant of the vector meson as a function of the square of the pion mass. The experimental points for the ρ and ϕ are also included.



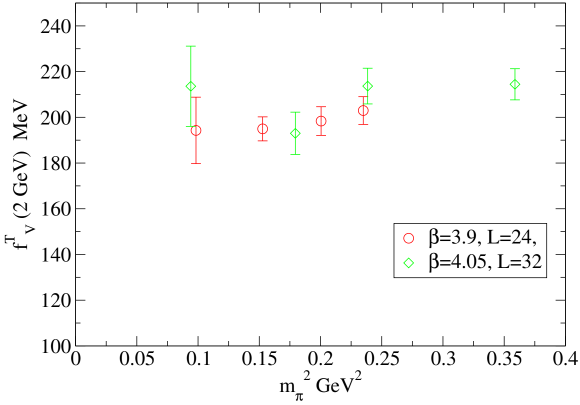
Leptonic decay constant of the ρ from LGT

$$f_{\rho^+}^{expt} \sim 208 \quad MeV \qquad f_{\rho^0}^{expt} \sim 216(5) \quad MeV$$

- Lewis and Woloshyn (hep-lat/9610027) obtained a result close to experimental result for the f_ρ in a quenched QCD calculation using the D234 improved action.
- QCDSF obtained (hep-lat/0509196) f_ρ = 256(9) MeV from n_f =2 lattice calculations with non-perturbatively improved clover action.
- Recently Hashimoto and Izubuchi (arXiv/0803.0186) obtained f_ρ^{phys} = 210(15) MeV from a n_f = 2 unquenched calculations that used domain wall fermions. However this calculation also found that r_0^{phys} = 0.549(9) fm, using the ρ mass to set scale.
- ETMC f_ρ^{phys} = 238(17) MeV (linear fits and only used the β - 3.9 data.)

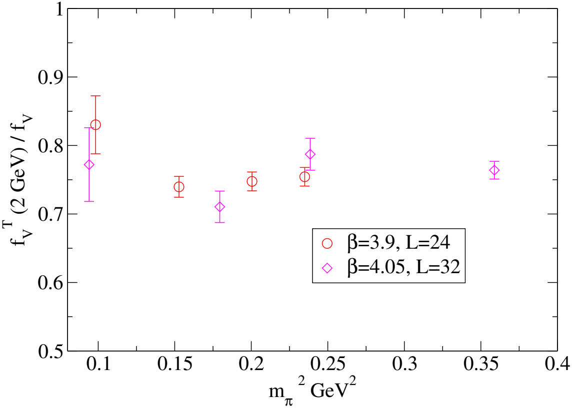
Results for f_ρ^{trans} (2 GeV)

The transverse decay constant of the vector meson as a function of the square of the pion mass.



Results for f_ρ^{trans} (2 GeV) / f_ρ

Ratio of transverse and leptonic decay constants of the vector meson as a function of the square of the pion mass.



Summary of transverse decay constant

Group	Method	$f_\rho^T(2\ \text{GeV})$ MeV	$\frac{f_\rho^T}{f_\rho}$
Ball et al.	sum rule	155(10)	0.74(3)
Becirevic et al.	quenched	150(5)	$0.72(2)^{+2}_{0}$
Braun et al.	quenched	154(5)	0.74(1)
QCDSF 1999	quenched	149(9)	-
QCDSF 2005	unquenched	168(3)	-
RBC-UKQCD	unquenched	143(6)	0.69(3)
ETMC	unquenched	184(15)	0.76(4)

- Only QCDSF and ETMC compute f_ρ^T on its own, all the others compute $\frac{f_\rho^T}{f_\rho}$ and then multiply by experiment value for f_ρ.
- $\frac{f_\rho^T}{f_\rho} = \frac{1}{\sqrt{2}}$ from large n_c limit from Cata and Mateu (arXiv:0801.4374)

KRSF relations (Physics Reports, 164 1988), 217), Bando et al.

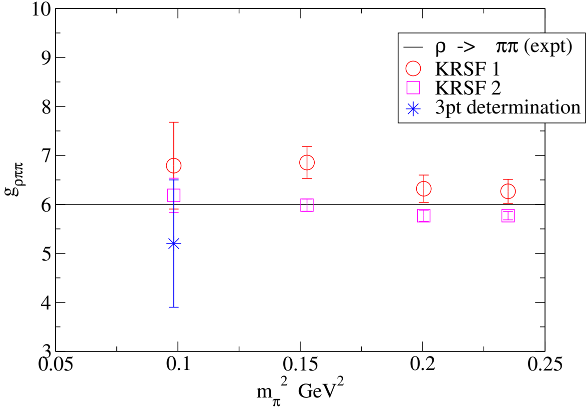
With our lattice data we can test the "famous" KRSF relations

$$f_\rho \frac{m_\rho}{\sqrt{2}} = f_\pi^2 g_{\rho\pi\pi} \quad \text{KRSF 1}$$

$$m_\rho^2 = f_\pi^2 g_{\rho\pi\pi}^2 \quad \text{KRSF 2}$$

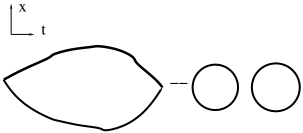
- I expect corrections of some sort ....
- Original derivation used PCAC relation on ρ decay.
- Related to vector meson dominance of pion form factor.
- The KRSF relations are built into some form of effective field theory of vector mesons, such as "hidden symmetry" or Georgi's vector limit of QCD (but extra 2 in KRSF2).
- Inspiration for some technicolor model building (arXiv:0906.0577), and ADS/CFT.

Mass dependence of KRSF



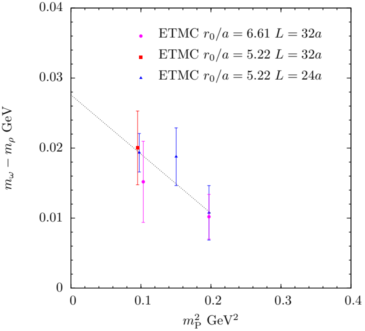
ω - ρ mass spliting from lattice QCD

- The ω is a light flavour singlet 1^{--} meson with mass 783 MeV (compare to $m_\rho = 776$ MeV).
- The lattice calculation needs disconnected diagrams. Similar calculation to that for η', but mass splitting is much smaller.
- Previous lattice QCD calculations, by RBC (15(194) MeV) and UKQCD (2(3) MeV), of ω-ρ mass splitting had big errors.
- Key advantage of ETM calculations is efficient algorithm for disconnected diagrams (arXiv:0803.0224) for twisted mass QCD.



The ω-ρ mass splitting

From ETM collaboration (arXiv:0902.3897)



$$m(\omega) - m(\rho) = 27(10) \quad \text{MeV}$$

compared to experiment of 7.2 MeV.

Isospin breaking and lattice QCD

Most lattice QCD calculations include 2 or 2+1 of sea quarks (2+1+1, ETMC and MILC in progress), and mostly no electromagnitsm included. However, a number of groups have reported results for isospin breaking quantities.

- (hep-lat/0407028) MILC collaboration $m_u/m_d = 0.43(8)$.
- (hep-lat/0605014) NPLQCD $M_n - M_p = 2.26 \pm 0.71$ MeV.
- Decay constant of a_0 meson (hep-lat/0604009)
- Formalism paper by Walker-Loud, arXiv:0904.2404

How? Fit mass dependence.

$$Q = Q^0 + Q^1(m_1 + m_2)$$

and use additional information on electromagnetism effects.

Applications of ω - ρ mixing

Charge symmetry operation

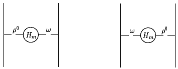
$$P_{cs} \mid d\rangle = \mid u\rangle \quad P_{cs} \mid u\rangle = - \mid d\rangle$$

Charge symmetry breaking (CSB) in nuclear physics, because

- u and d quarks have different mass
- u and d have different charges

$$a^N_{nn} = -18.9 \pm 0.4 \ fm \quad a^N_{pp} = -17.3 \pm 0.4 \ fm$$

Properties of mirror nuclei. But what is the mechanism?



ω - ρ mixing from lattice QCD (ETMC arXiv:0902.3897)

The mixing (EM from hep-ph/9607462 Bijnens et al.) can be defined from a mass matrix (with basis states $(\bar{u}\gamma_i u \pm \bar{d}\gamma_i d)/\sqrt{2}$):

$$\begin{pmatrix} m_\rho & T_{\omega\rho} \\ T_{\omega\rho} & m_\omega \end{pmatrix} .$$

$$\begin{aligned} T_{\omega\rho} &= (\frac{dm_\rho}{dm_q} + \frac{dm_\omega}{dm_q}) \frac{m_u - m_d}{4} \\ T_{\omega\rho} &\approx (\frac{2dm_\rho}{dm_q} + \frac{d(m_\omega - m_\rho)}{dm_q}) \frac{m_u - m_d}{4} \end{aligned} \tag{1}$$

Then use $\frac{dm_\rho}{dm_\pi^2} \approx \frac{1}{2m_\rho}$ and $\frac{dm_\pi^2}{dm_q} \approx \frac{m_\pi^2}{m_q}$, $T_{\omega\rho} =$ -3.6 (1 + 7(7) % disc) MeV

Conclusions

- Lattice QCD calculation of α_s as an example of a precision lattice QCD calculation. Need α_s from other formulations.
- α_s is an example of need accuracy of order 1 % to see evidence of BSM physics.
- Chiral extrapolations of ρ mass and decay constant is a problem for us at least.
- Need to reduce statistical errors on ρ mass. Probably need bigger ensembles, but also work on measurement techniques.
- Starting to compute isospin violating quantities on the lattice. Electromagnetism included by some groups (RBC, MILC).
- Lattice QCD calculations of "gold plated" quantities are accurate, but higher accuracy is required to see BSM physics.
- There is a FIRM deadline 2015 for improving the accuracy of lattice QCD calculations of properties of resonances.