Applications of SU(3) ChPT including lattice data close to the SU(3) symmetric point

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Motivation

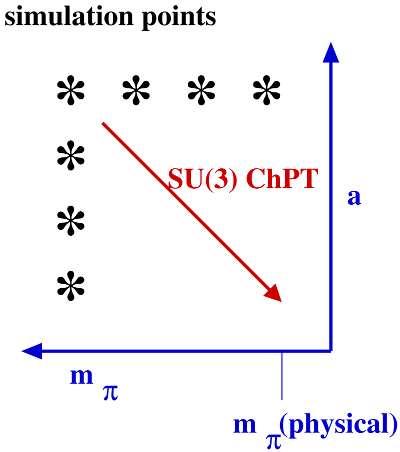
Why should one still care about SU(3) ChPT as a lattice physicist ?

- It is a priori not clear whether SU(3) ChPT is an effective or ineffective field theory
- One can meanwhile simulate at physical masses
- One can simulate large volumes

Because !

- Lattice simulations can help to improve SU(3) ChPT, important for low and medium energy hadron physics
- The continuum limit of lattice simulations dominates the systematic uncertainties for many observables.
  $a < 0.05$ fm is hardly possible for Wilson fermions due to exploding topological autocorrelation times.

The CLS strategy for simulations with open boundary conditions



convergence of SU(3) ChPT is generally bad because there is no clear seperation of scales

$$M_{\bar{s}s}^2 = 2M_K^2 - M_\pi^2 \approx (700\ \mathrm{MeV})^2$$

comparable to the hard scale of ~ 1 GeV

Options:

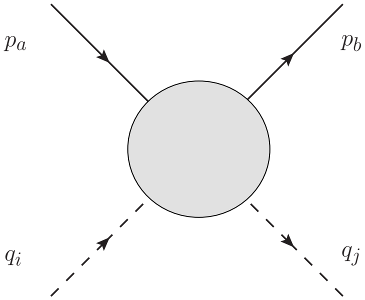
- Forget about SU(3) ChPT
- Improve SU(3) ChPT: Many suggestions but no breakthrough
- Improve the determination of LECs by expanding around the SU(3) symmetric (!) [QCDSF]

$$\begin{aligned} m_B &= m_\star(!) + \mathcal{O}(m_s - m_\ell) \qquad \text{versus} \\ m_B &= m_0(?) + \mathcal{O}(M_{\bar{s}s}^2) \end{aligned}$$

Illustrating the problem:

Mai, Bruns, Kubis and Meißner; 0905.2810

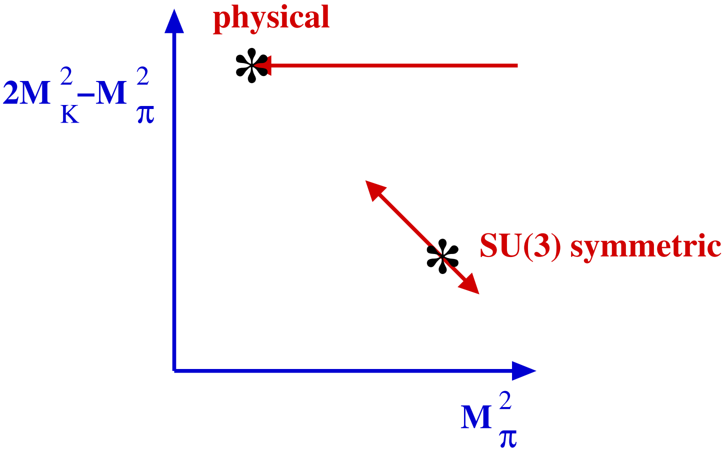
a calculation of the S-wave meson-baryon scattering lengths at one loop level and up to third chiral order.



Channel	=	$\mathcal{O}(q^1)$	$+\mathcal{O}(q^2)$	$+\mathcal{O}(q^3)_{IR}$	$\sum_{IR}$
$a_{\pi N}^{(3/2)}$	=	-0.12	$+0.05^{+0.06}_{-0.06}$	$+0.04^{+0.01}_{-0.01}$	$-0.04^{+0.07}_{-0.07}$
$a_{\pi N}^{(1/2)}$	=	$+0.21$	$+0.05^{+0.06}_{-0.06}$	$-0.19^{+0.01}_{-0.01}$	$+0.07^{+0.07}_{-0.07}$
$a_{\pi \Xi}^{(3/2)}$	=	-0.12	$+0.04^{+0.06}_{-0.07}$	$+0.10^{+0.00}_{+0.00}$	$+0.02^{+0.06}_{-0.07}$
$a_{\pi \Xi}^{(1/2)}$	=	$+0.23$	$+0.04^{+0.06}_{-0.07}$	$-0.24^{+0.02}_{-0.03}$	$+0.02^{+0.08}_{-0.10}$
$a_{\pi \Sigma}^{(2)}$	=	-0.24	$+0.10^{+0.02}_{-0.03}$	$+0.15^{+0.02}_{-0.01}$	$+0.01^{+0.04}_{-0.04}$
$a_{\pi \Sigma}^{(1)}$	=	$+0.22$	$+0.09^{+0.15}_{-0.15}$	$-0.21^{+0.01}_{-0.02}$	$+0.10^{+0.16}_{-0.17}$
$a_{\pi \Sigma}^{(0)}$	=	$+0.46$	$+0.11^{+0.15}_{-0.17}$	$-0.47^{+0.02}_{-0.03}$	$+0.10^{+0.17}_{-0.19}$
$a_{\pi \Lambda}^{(1/2)}$	=	-0.01	$+0.03^{+0.03}_{-0.03}$	$-0.03^{+0.01}_{-0.01}$	$-0.01^{+0.04}_{-0.04}$
$a_{KN}^{(1)}$	=	-0.45	$+0.60^{+0.14}_{-0.20}$	$-0.48^{+0.18}_{-0.12}$	$-0.33^{+0.32}_{-0.32}$
$a_{KN}^{(0)}$	=	$+0.04$	$-0.15^{+0.59}_{-0.61}$	$+0.13^{+0.05}_{-0.03}$	$+0.02^{+0.64}_{-0.64}$
$a_{\bar{K}N}^{(1)}$	=	$+0.20$	$+0.22^{+0.36}_{-0.40}$	$-0.26^{+0.02}_{-0.03} + 0.18i$	$+0.16^{+0.39}_{-0.44} + 0.18i$
$a_{\bar{K}N}^{(0)}$	=	$+0.53$	$+0.97^{+0.42}_{-0.51}$	$-0.40^{+0.05}_{-0.08} + 0.22i$	$+1.11^{+0.47}_{-0.59} + 0.22i$
$a_{K\Sigma}^{(3/2)}$	=	-0.31	$+0.33^{+0.41}_{-0.41}$	$-0.30^{+0.11}_{-0.07} + 0.12i$	$-0.28^{+0.52}_{-0.49} + 0.12i$
$a_{K\Sigma}^{(1/2)}$	=	$+0.47$	$+0.19^{+0.50}_{-0.57}$	$+0.20^{+0.05}_{-0.07} + 0.01i$	$+0.87^{+0.55}_{-0.64} + 0.01i$
$a_{\bar{K}\Sigma}^{(3/2)}$	=	-0.22	$+0.24^{+0.39}_{-0.44}$	$-0.35^{+0.05}_{-0.03} + 0.08i$	$-0.33^{+0.44}_{-0.47} + 0.08i$
$a_{\bar{K}\Sigma}^{(1/2)}$	=	$+0.34$	$+0.38^{+0.55}_{-0.52}$	$+0.27^{+0.04}_{-0.06} + 0.01i$	$+0.98^{+0.59}_{-0.59} + 0.01i$
$a_{K\Xi}^{(1)}$	=	$+0.15$	$+0.34^{+0.43}_{-0.43}$	$-0.02^{+0.00}_{-0.01} + 0.17i$	$+0.48^{+0.43}_{-0.43} + 0.17i$
$a_{K\Xi}^{(0)}$	=	$+0.66$	$+0.98^{+0.45}_{-0.58}$	$-0.62^{+0.06}_{-0.09} + 0.14i$	$+1.02^{+0.51}_{-0.68} + 0.14i$
...	...	...	...	...	...

Full result for the fit to $a_{\pi N}^{+}$ and $a_{KN}^{(1)}$ [in units of fm].

SU(3) ChPT fit to QCDSF data. 1102.5300 etc.
In future we plan to use CLS data including data at the SU(3) symmetric point

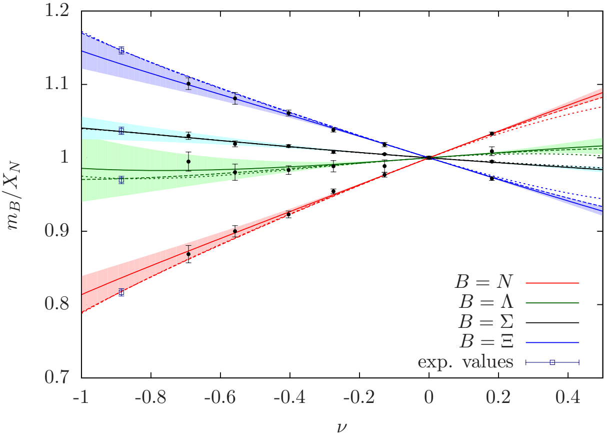


The ChPT was worked out in: M. Frink and U. Meißner, hep-lat/0404018

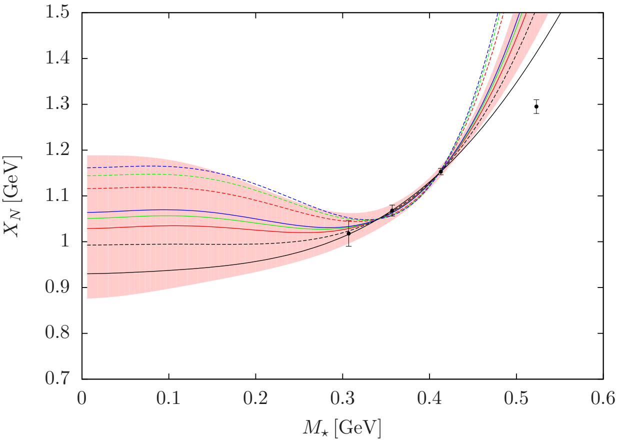
The relevant terms are:

$$
\begin{aligned}
\mathcal{L}_{\phi B}^{(1)} &= \langle \bar{B}(i\not{D} - m_0)B\rangle + \frac{D}{2}\langle \bar{B}\gamma^{\mu}\gamma_5\{u_{\mu}, B\}\rangle + \frac{F}{2}\langle \bar{B}\gamma^{\mu}\gamma_5[u_{\mu}, B]\rangle \\
&+ b_0\langle \bar{B}B\rangle\langle \chi_+\rangle + b_D\langle \bar{B}\{\chi_+, B\}\rangle + b_F\langle \bar{B}[\chi_+, B]\rangle + \dots \\
\mathcal{L}_{\phi B}^{(4)} &= d_1\langle \bar{B}[\chi_+, [\chi_+, B]]\rangle + d_2\langle \bar{B}[\chi_+, \{\chi_+, B\}]\rangle + d_3\langle \bar{B}\{\chi_+, \{\chi_+, B\}\}\rangle \\
&+ d_4\langle \bar{B}\chi_+\rangle\langle \chi_+ B\rangle + d_5\langle \bar{B}[\chi_+, B]\rangle\langle \chi_+\rangle \\
&+ d_6\langle \bar{B}B\rangle\langle \chi_+\rangle\langle \chi_+\rangle + d_7\langle \bar{B}B\rangle\langle \chi_+^2\rangle
\end{aligned}
$$

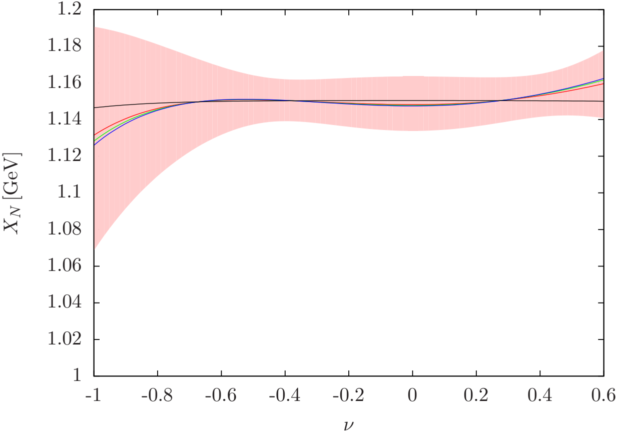
$$
\begin{aligned}
\mathcal{L}_{\phi B}^{(2)} &= b_{D/F}\langle \overline{B}\,[\chi_+, B]_\pm\rangle + b_0\langle \overline{B}B\rangle\langle\chi_+\rangle \\
&+ b_{1/2}\langle \overline{B}\left[u_\mu, [u^\mu, B]_\mp\right]\rangle + b_3\langle \overline{B}\,\{u_\mu, \{u^\mu, B\}\}\rangle + b_4\langle \overline{B}B\rangle\langle u_\mu u^\mu\rangle \\
&+ i\Big(b_{5/6}\langle \overline{B}\sigma^{\mu\nu}\,[[u_\mu, u_\nu]\,, B]_\mp\rangle + b_7\langle \overline{B}\sigma^{\mu\nu}u_\mu\rangle\langle u_\nu B\rangle\Big) \\
&+ \frac{i\,b_{8/9}}{2m_0}\Big(\langle \overline{B}\gamma^\mu\left[u_\mu, [u_\nu, [D^\nu, B]]_\mp\right]\rangle + \langle \overline{B}\gamma^\mu\left[D_\nu, [u^\nu, [u_\mu, B]]_\mp\right]\rangle\Big) \\
&+ \frac{i\,b_{10}}{2m_0}\Big(\langle \overline{B}\gamma^\mu\,\{u_\mu, \{u_\nu, [D^\nu, B]\}\}\rangle + \langle \overline{B}\gamma^\mu\,[D_\nu, \{u^\nu, \{u_\mu, B\}\}]\rangle\Big) \\
&+ \frac{i\,b_{11}}{2m_0}\Big(2\langle \overline{B}\gamma^\mu\,[D_\nu, B]\rangle\langle u_\mu u^\nu\rangle + \langle \overline{B}\gamma^\mu B\rangle\langle [D_\nu, u_\mu]\,u^\nu + u_\mu\,[D_\nu, u^\nu]\rangle\Big)
\end{aligned}
$$



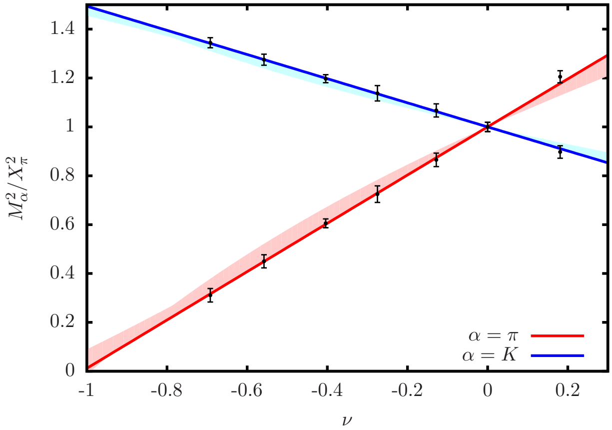
The fan plot for baryon masses $X_N = (M_N + M_\Sigma + M_\Xi)/3$ and $\nu = (M_\pi^2 - X_\pi^2)/X_\pi^2$ and $X_\pi^2 = (2M_K^2 + M_\pi^2)/3$



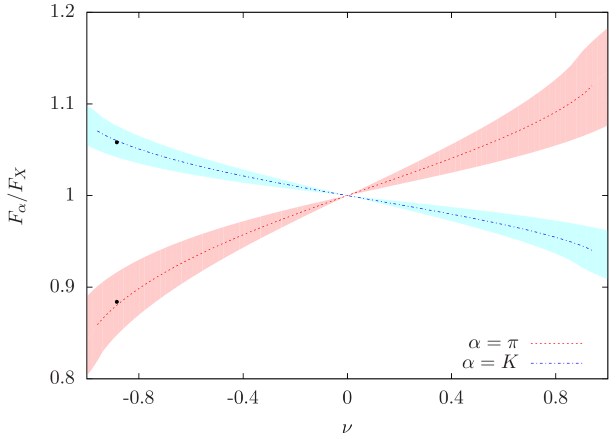
Quality of extrapolation along the SU(3) symmetric line $M_\star = M_\pi = M_K = M_\eta$. Less constraint than for fixed $M_{singlet}$. More simulations needed to fix LECs.



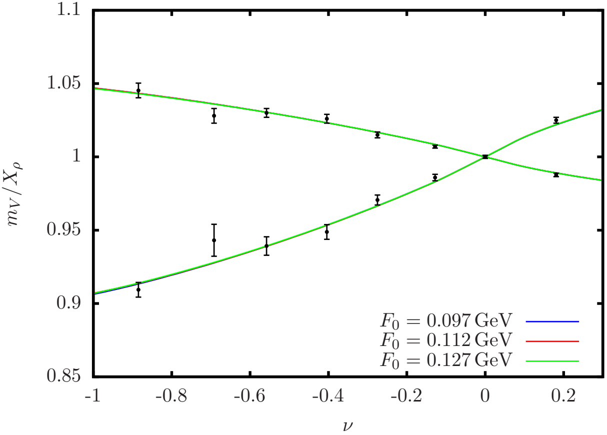
Quality of determination of ChPT parameters: X_N as a function of ν



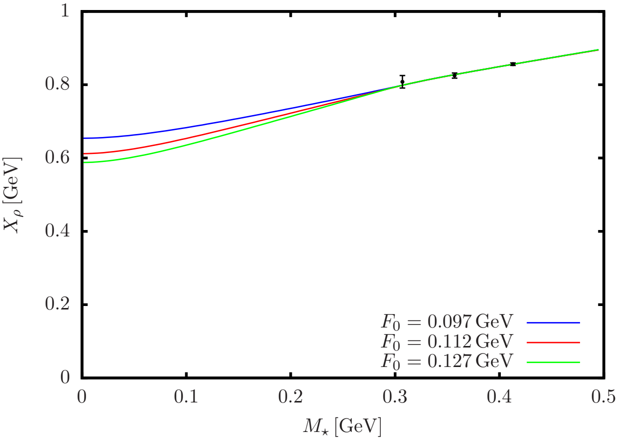
The pseudoscalar mesons with LECs from Bazavov et al.
[MILC] 1012.0868 no fitting !!!



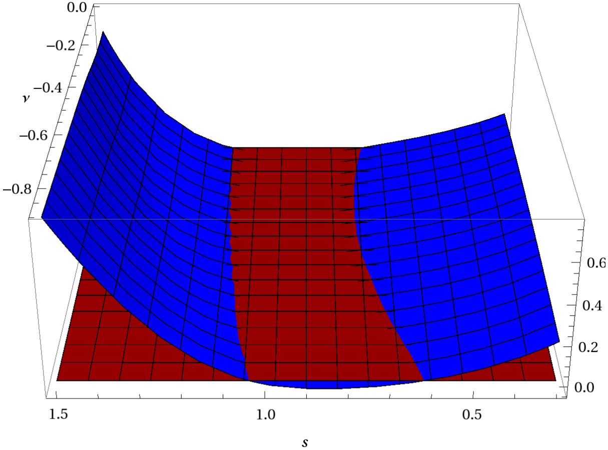
Fan plot for the meson decay constants F_K and F_π



Fanplot for vector mesons: $X_\rho = (2M_K^* + M_\rho)/3$
vector mesons are difficult in ChPT: decay $\sim$ imaginary part, singlett-octet mixing



Quality of determination of ChPT parameters: X_ρ as a function of $M_\star = m_\pi = m_K = m_\eta$



The determinant of the singlet-octet mixing matrix. The zero's correspond to poles, which correspond to ω and ϕ.

Expansion around the chiral limit $\Rightarrow$ no stable results

(s=Mandelstam s)

Conclusion

- In contrast to expansion around the chiral limit, expansion around the SU(3) symmetric point leads to convergence of SU(3) ChPT for all quantities studied
- Therefore, lattice input can help to better determine SU(3) ChPT LECs$\Rightarrow$ Impact on real time phenomenology
- SU(3) ChPT should be effective to extrapolate CLS data to physical masses at small a