From Strange to Charmed Baryons Using $N_f = 2$ Twisted Mass QCD

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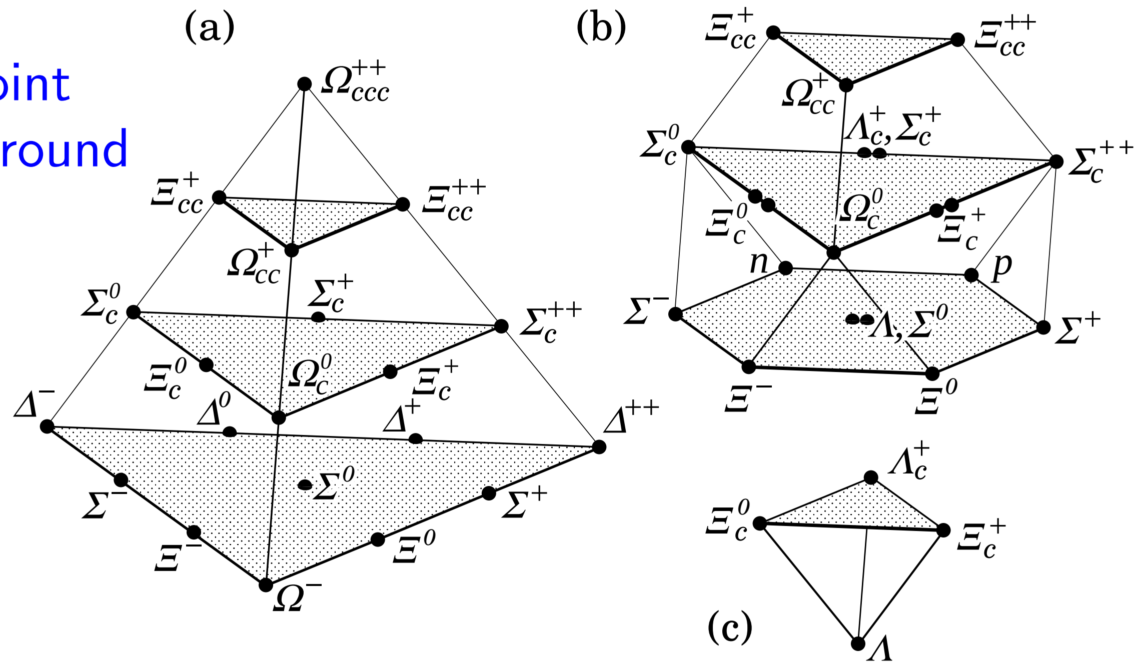
Setup

- ETMC configurations with $N_f = 2$ dynamical light flavours at three values of $a \in \{0.051, 0.064, 0.080\}\text{fm}$ and physical volume $L \sim 2.0 \div 2.4\text{fm}$

- light sea quark masses corresponding to $M_\pi \in [290, 520]\text{MeV}$

- partially quenched valence strange/charm (in the following called "heavy") quarks $\Rightarrow$ $M_K \in [530, 710]\text{MeV}$ and $M_D \in [1.80, 2.40]\text{GeV}$. In all 40 different combinations (M_π,M_{hl}).

- Octet and decuplet baryon two-point correlators corresponding to the ground floor and the rear wall of the two 20plets. For the charmed baryons with $J = 1/2$: $\Lambda[udc]$, $\Sigma[udc]$, $\Xi[ucc]$ and with $J = 3/2$: $\Sigma^*[udc]$, $\Xi^*[ucc]$, $\Omega[ccc]$



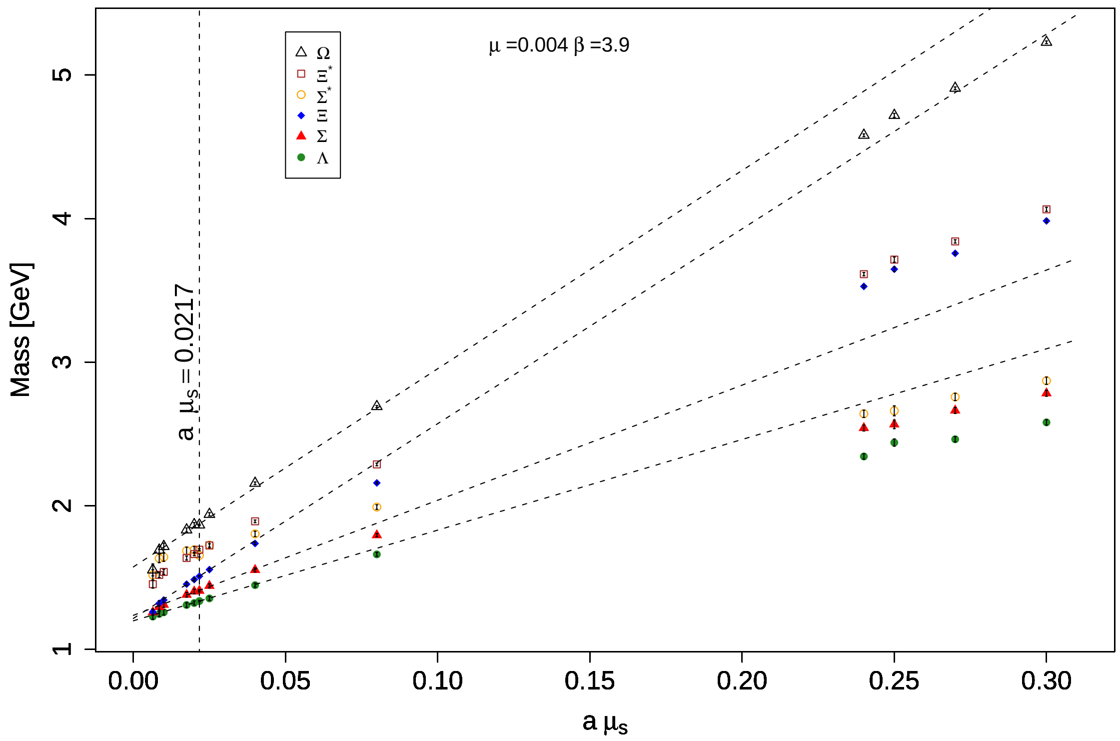
Motivations

- Extend the study of the strange baryon spectrum in [Alexandrou *et al.*, 2009] to the finest lattice spacing $a \simeq 0.051$ to better asses the size of lattice artefacts for strange baryons.

- Investigate the size of lattice artefacts in the spectrum of charmed baryons (with one, two and three charm quarks).

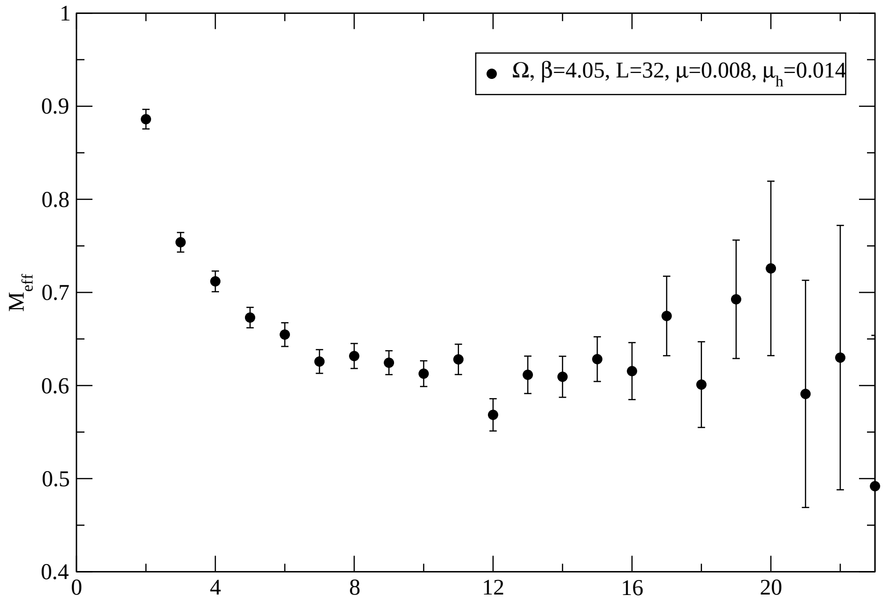
- Investigate the strange and the charm mass dependence and the crossover between the two regions.

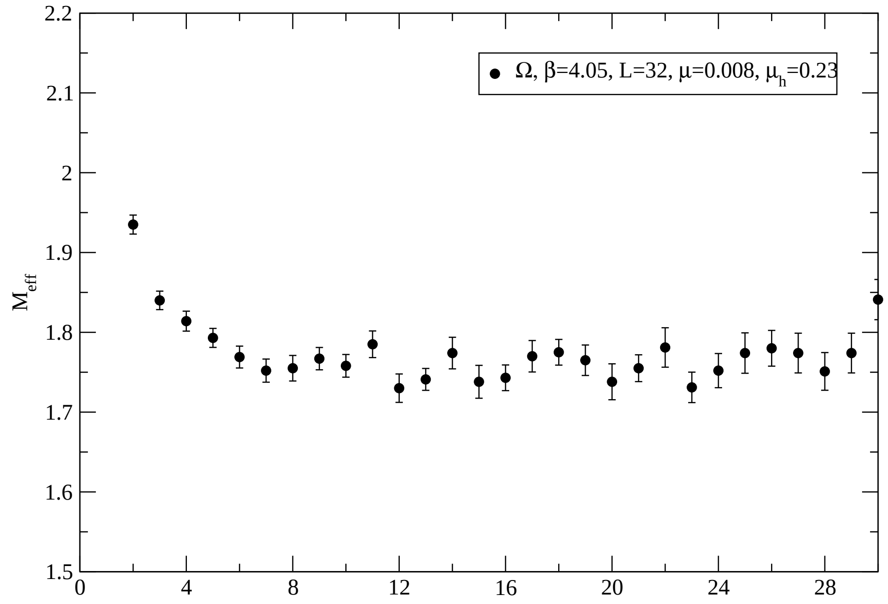
  At $a = 0.080\mathrm{fm}$ and $M_\pi \simeq 340\mathrm{MeV}$ the "heavy" quark mass (m_h) dependence of the baryon spectrum looks like:



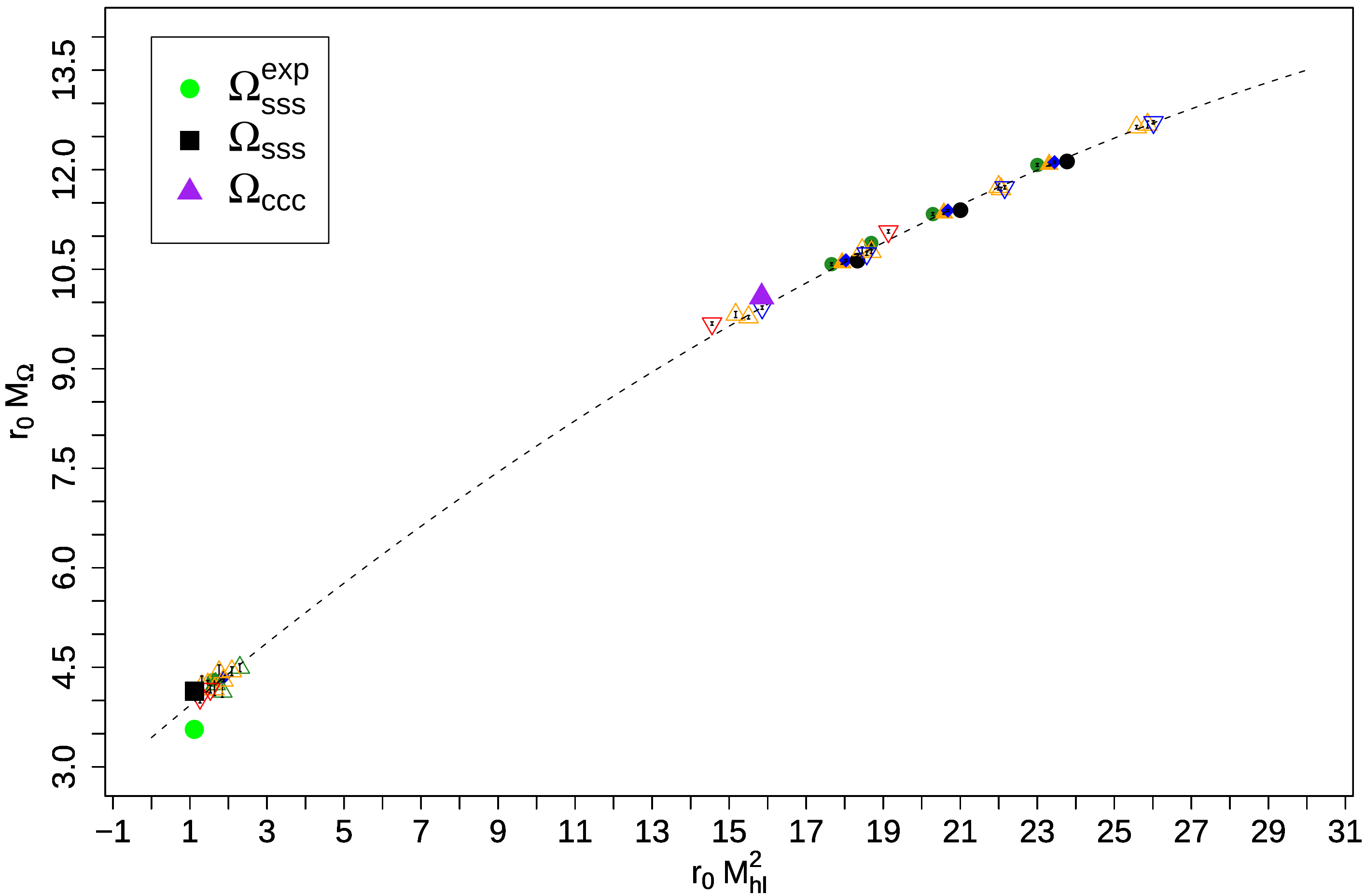
- Is the behavior with m_h affected or not by large lattice artefact in the charm region? Notice e.g. that the splitting between $J = 1/2$ and $J = 3/2$ states (Σ/Σ^* and Ξ/Ξ^*) diminishes with the increase of m_h as predicted by quark models.

$\Omega_{[sss]}$ and $\Omega_{[ccc]}$





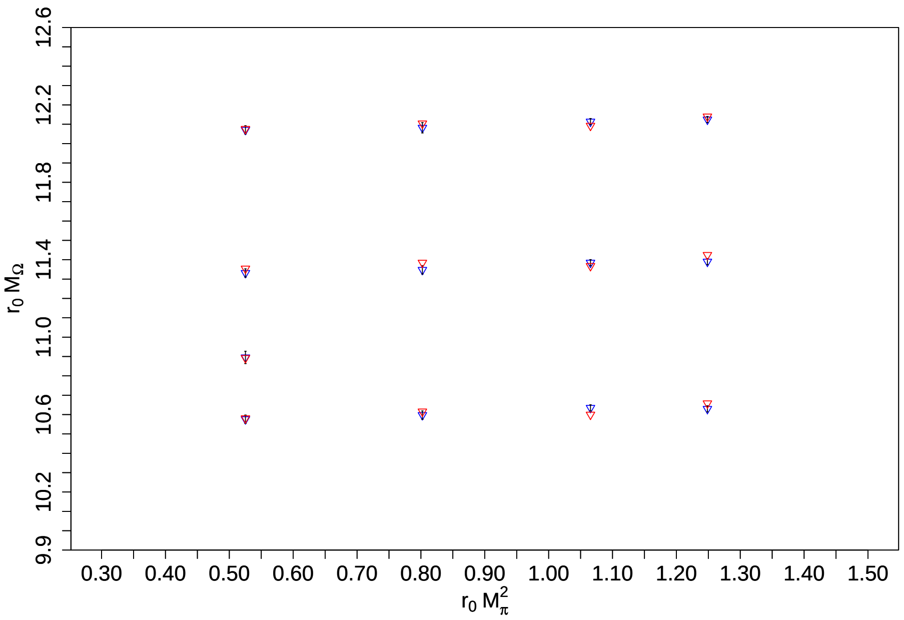
$$\Delta M_{\rm eff}(t) \propto \exp((M_\Omega - \tfrac{3}{2} M_{\bar{h}h})t)$$

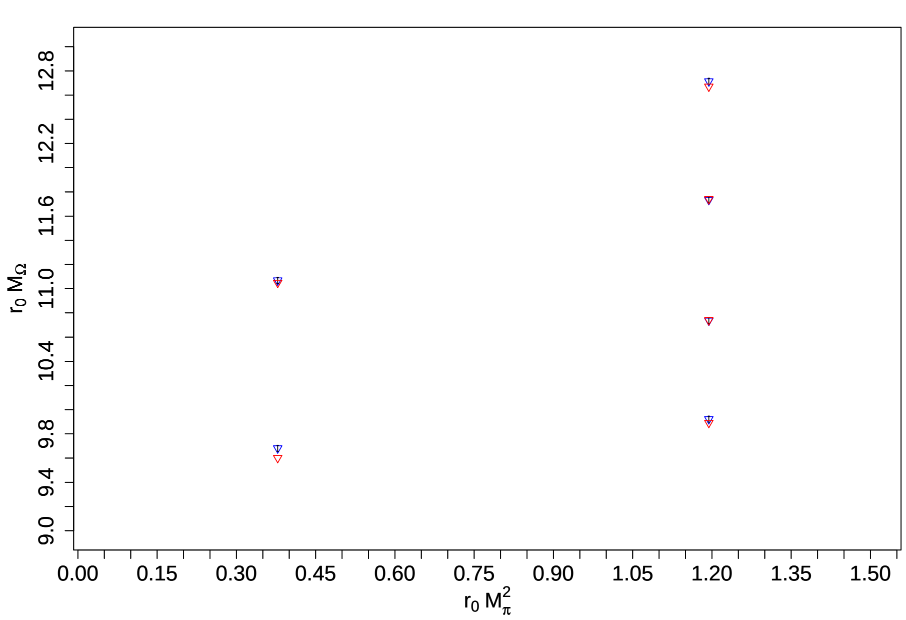


- Combined fit of the form

$$M_\Omega = M_0 + AM_\pi^2 + BM_{\rm hl}^2 + CM_{\rm hl}^4$$

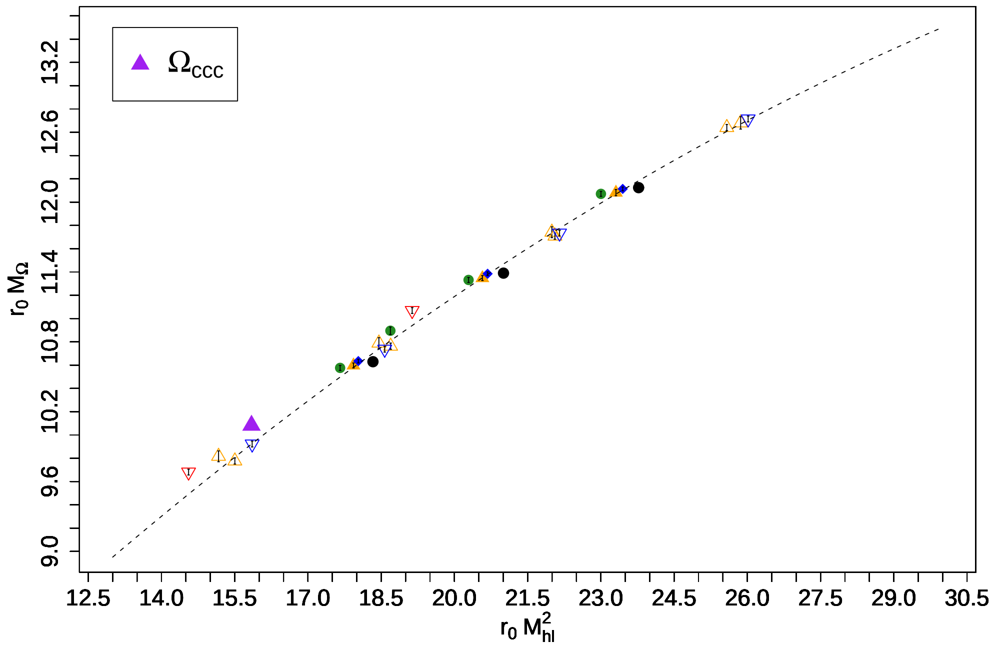
- 40 data points, $\chi^2_{\rm d.o.f.} = 1.87$: no evidence of lattice artefacts!





- extrapolation to the physical (M_π, M_K) point gives $M_{\Omega_s} = 1.94(15)\text{GeV}$ to be compared with the $M_{\Omega_s}^{\text{exp}} = 1.672\text{GeV}$

- extrapolation to the physical (M_π, M_D) point gives $M_{\Omega_c} = 4.73(35)\text{GeV}$ Experimental value missing.



- Check: combined fit of the form only in the strange region

$$M_\Omega = \bar{M}_0 + \bar{A} M_\pi^2 + \bar{B} M_{\rm hl}^2$$

- 13 data points, $\chi^2_{\rm d.o.f.} = 1.56$: $\bar{M}_0, \bar{A}, \bar{B}$ perfetctly compatible with M_0, A, B

- Remark: very mild dependence of M_Ω on the light quark mass. It can be well parametrized in terms of the combination $2M_{\rm hl}^2 - M_\pi^2 \propto m_h$ at leading order in χPT:

$$M_\Omega = M_0 + A(2M_{\rm hl}^2 - M_\pi^2) + B(2M_{\rm hl}^2 - M_\pi^2)^2$$

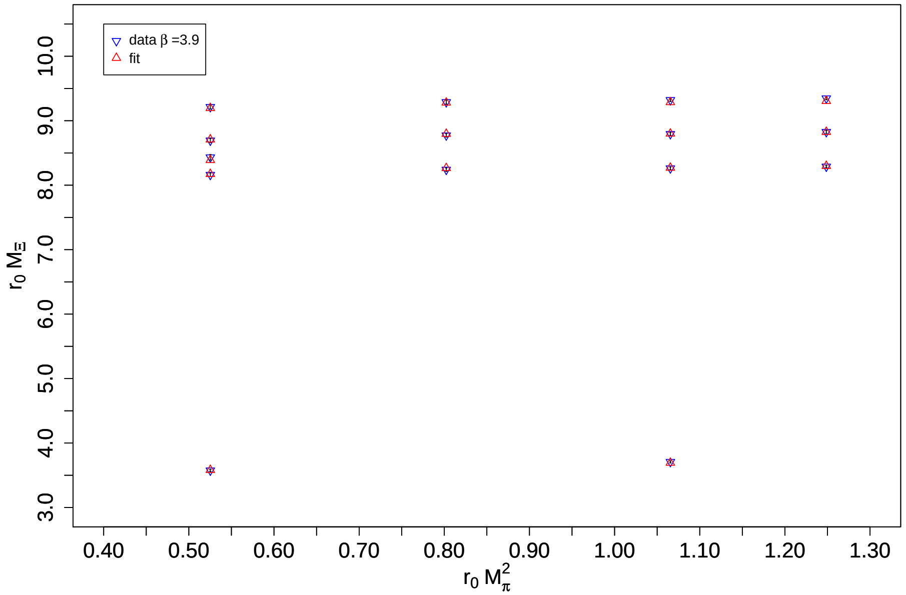
- M_{Ω_s} 15% larger than exp. value. No signs of lattice artefacts. Effect due to the chiral extrapolation? Partial quenching? Contamination by excited states?

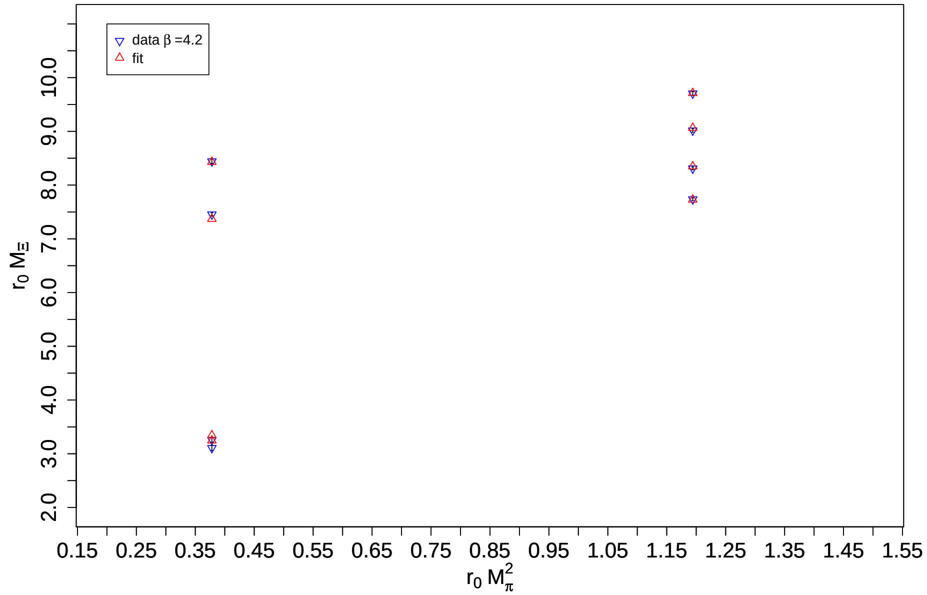
$\Xi_{[uss]}$ and $\Xi_{[ucc]}$

- Twisted mass QCD breaks isospin symmetry $\Rightarrow \Xi_s^0$ and Ξ_s^- are not degenerate.

- Combined fit to M_{Ξ^0} and M_{Ξ^-} with the same continuum part:

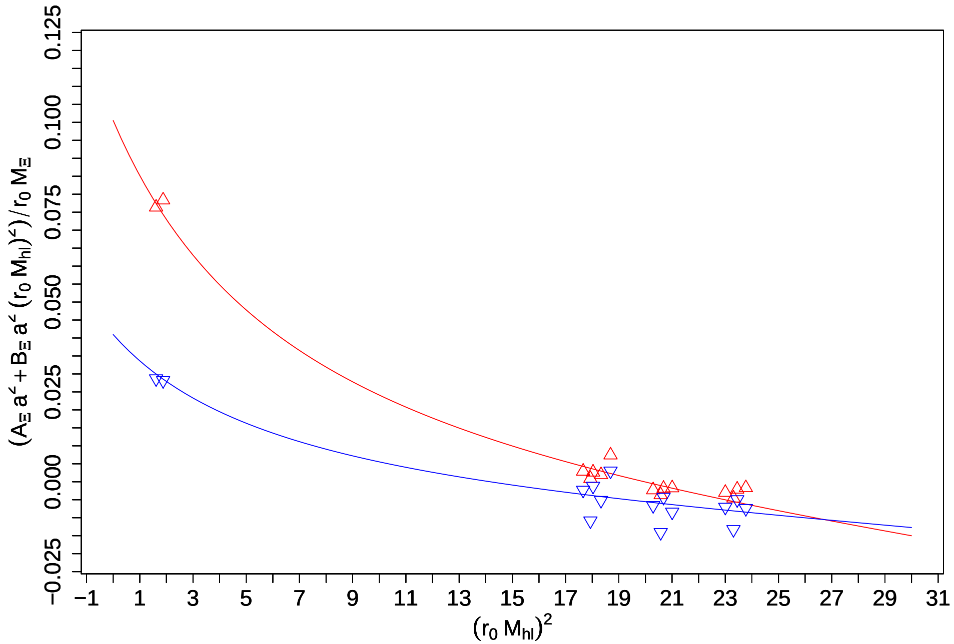
$$M_{\Xi\{0,-\}} = M_0 + AM_\pi^2 + DM_\pi^3 + BM_{\rm hl}^2 + CM_{\rm hl}^4 + A_{\{0,-\}}a^2 + B_{\{0,-\}}a^2M_{\rm hl}^2$$

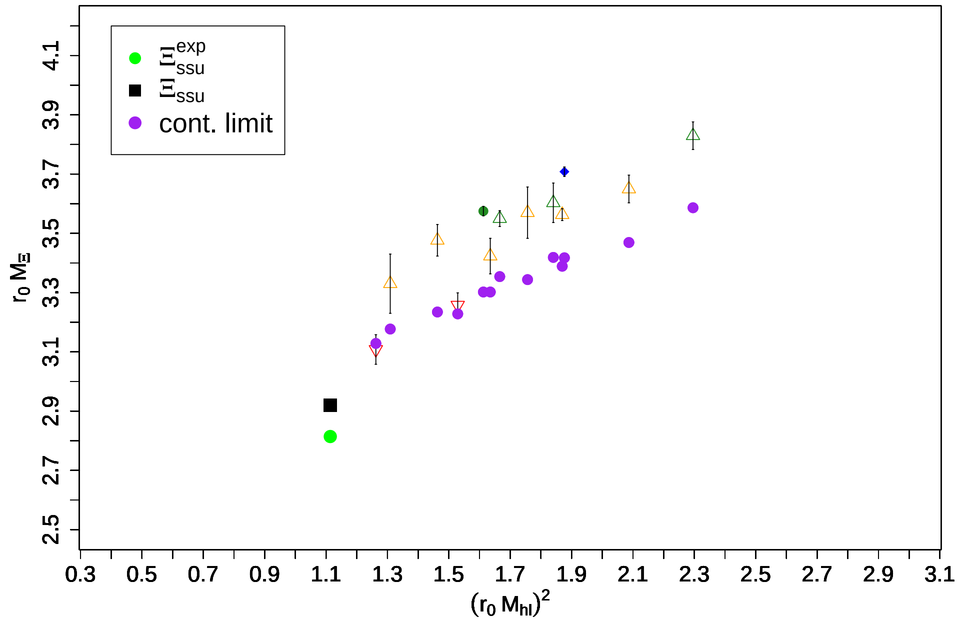




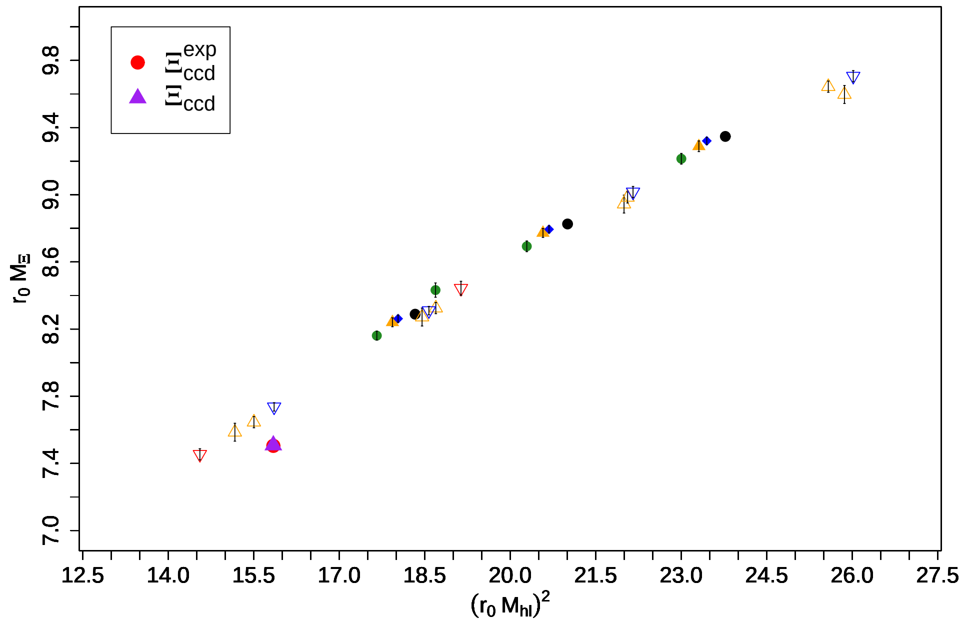
- 80 data points, $\chi^2_{\rm d.o.f.} = 1.77$, $A_0 > A_- > 0$ and $B_0 < B_- < 0$

- $\Rightarrow B_{\{0,-\}}a^2M_{\rm hl}^2$ compensate $A_{\{0,-\}}a^2$ when $M_{\rm hl}$ increases: artefacts are larger in the strange region!





- extrapolation to the physical (M_π, M_K) point gives $M_{\Xi_s} = 1.37(12)\text{GeV}$ to be compared with $M_{\Xi_s}^{\text{exp}} = 1.32\text{GeV}$
- extrapolation to the physical (M_π, M_D) point gives $M_{\Xi_c} = 3.52(25)\text{GeV}$ in perfect agreement with $M_{\Xi_c}^{\text{exp}} = 3.52\text{GeV}$

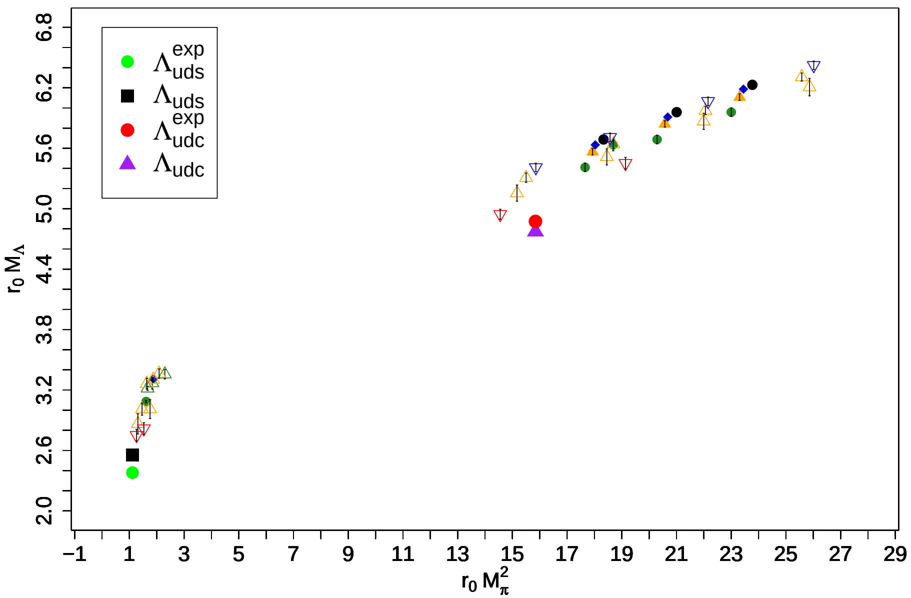


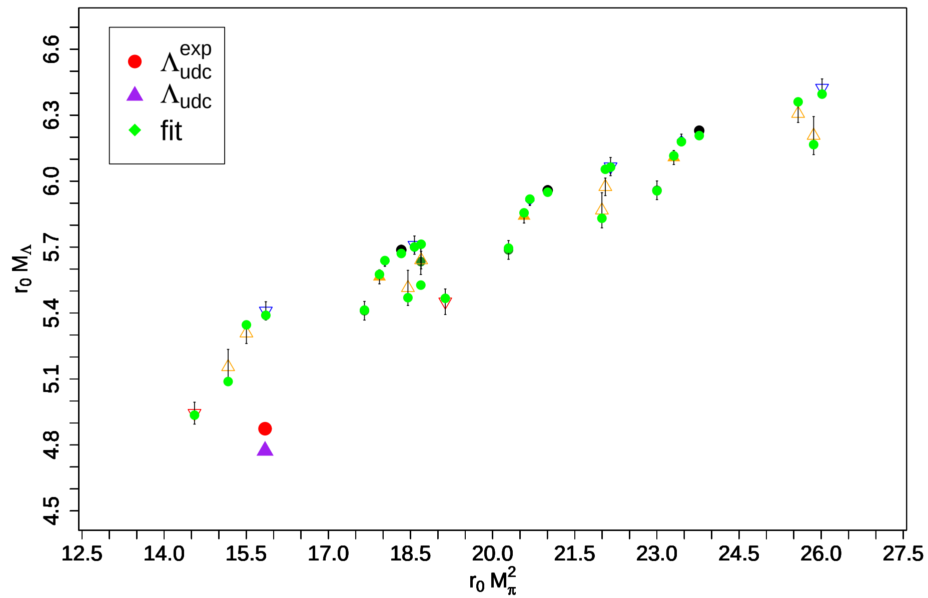
$\Lambda_{[uds]}$ and $\Lambda_{[udc]}$

- Combined fit of the form

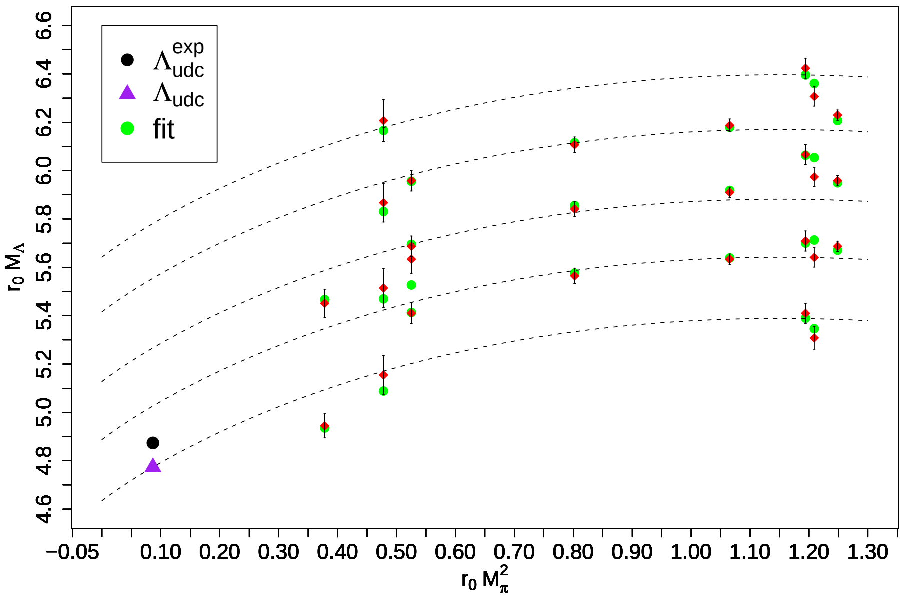
$$M_\Lambda = M_0 + AM_\pi^2 + BM_{\rm hl}^2 + CM_{\rm hl}^4 + DM_\pi^3$$

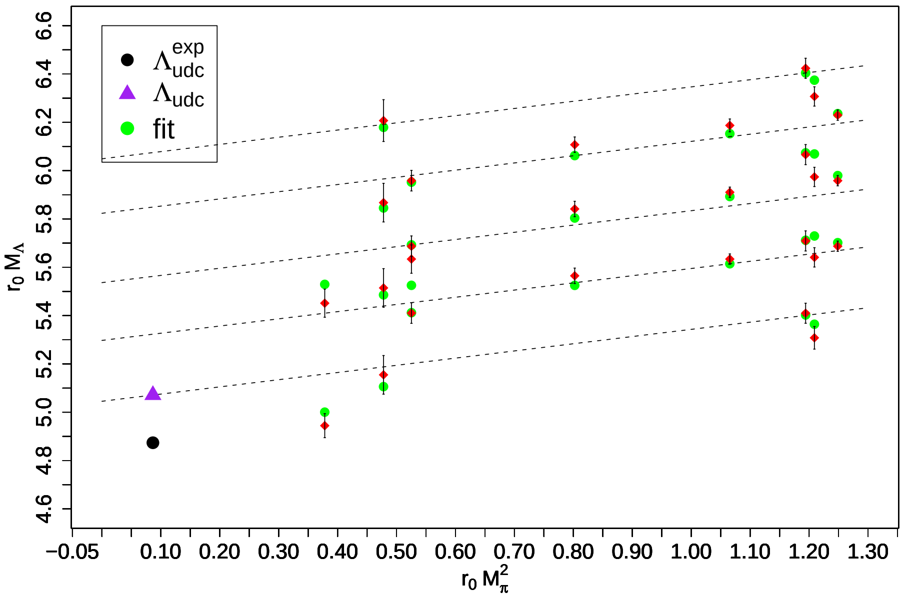
- 40 data points, $\chi^2_{\rm d.o.f.} = 1.01$: no evidence of lattice artefacts!





- Strong dependence on M_π, term in M_π^3 reduces $\chi^2_{\rm d.o.f.}$ of a factor 0.5.
- Chiral extrapolation is critical:





- extrapolation to the physical (M_π, M_K) point gives $M_{\Lambda_s} = 1.20(10)\mathrm{GeV}$ to be compared with $M_{\Lambda_s}^{\rm exp} = 1.116\mathrm{GeV}$
- extrapolation to the physical (M_π, M_D) point gives $M_{\Lambda_c} = 2.24(18)\mathrm{GeV}$ in good agreement with $M_{\Lambda_c}^{\rm exp} = 2.286\mathrm{GeV}$

Conclusions and outlook

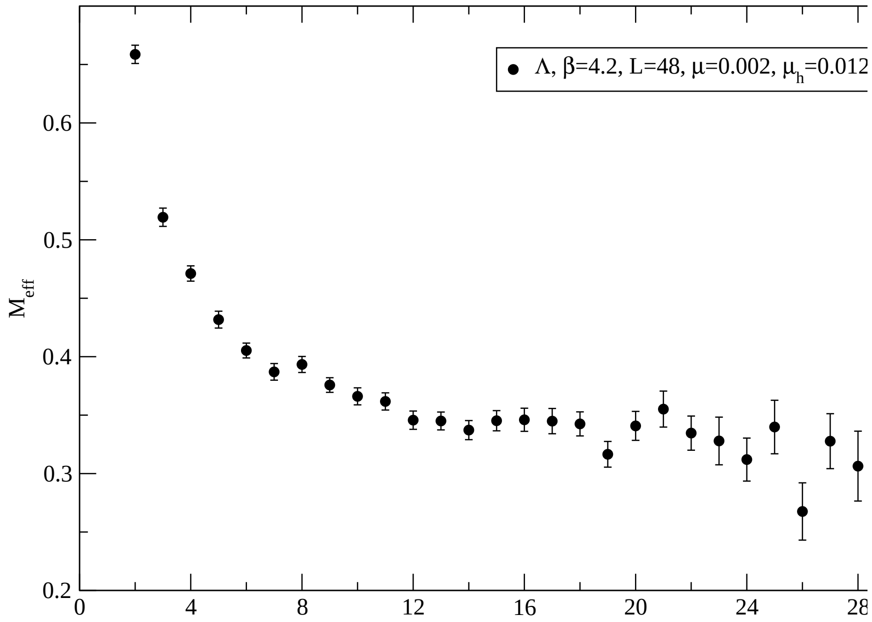
- for the cases addressed in this preliminary study, lattice artefacts are always small (negligible) in both the strange and the charm regions and only in the case of the Ξ they give a significant contribution (in the strange region).

- the chiral extrapolation in the light quarks confirms to be critical and a term of order M_π^3 is needed for both Ξ and Λ (it is particularly evident in this last case).

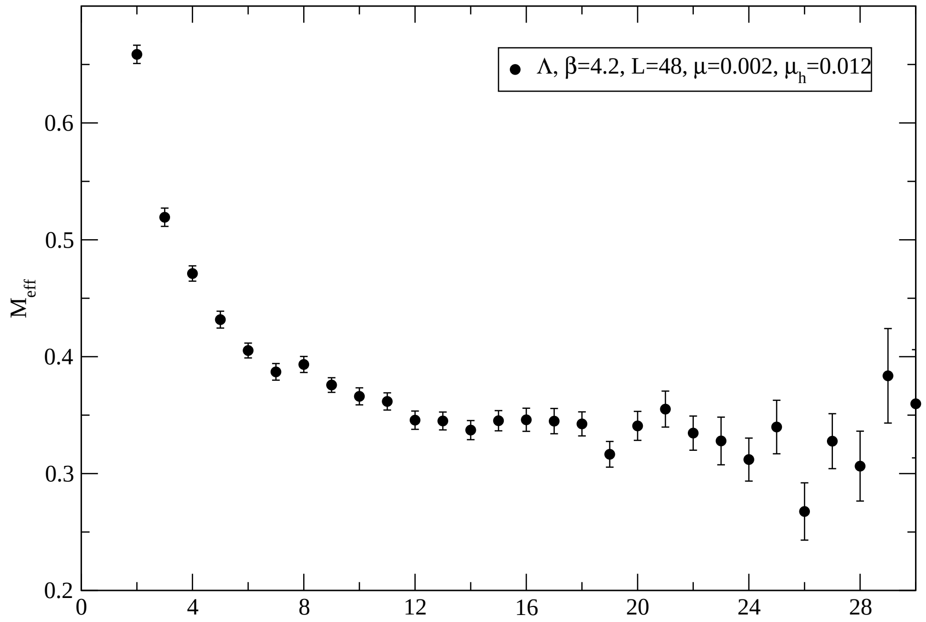
- our extended analysis confirms the results of [Alexandrou *et al.*, 2009]. M_Ω turns out to be still in desagreement with the experimental value but the source of this discrepancy seems unrelated to the scaling to the continuum limit.

- results for the charmed M_{Ξ_c} and M_{Λ_c} nicely agree with exp. results. We got moreover a prediction for M_{Ω_c}.

- we are extending this preliminary analysis the other charmed baryons and we are also increasing the statistics of many ensembles. We have also computed correlators to extract strange-charmed baryons. A complete analysis will be performed in the next future.



Λ, β=4.2, L=48, μ=0.002, μh=0.012
Meff



Λ, β=4.2, L=48, μ=0.002, μh=0.012
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