Hadron Spectroscopy from lattice QCD simulations

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Extraction of the mass spectrum

We saw $C(t) = \sum_n |Z_n|^2 e^{-E_n t}$, which at large times, $C(t) \to |Z_0|^2 e^{-E_0 t}$

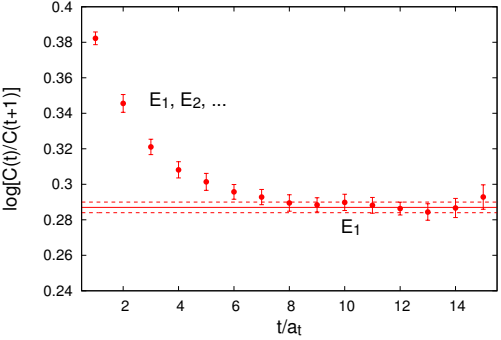
Note $e^{-E_n t} = e^{-aE_n . t/a}$

Effective mass defined as $m_{eff} = \frac{1}{dt} \log[\frac{C(t)}{C(t+dt)}]$

Mass extraction:
Fits $C(t)$ across multiple time slices.

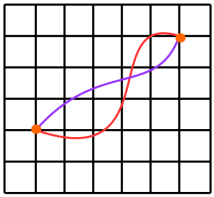
Ground states:
Single exponential fit forms

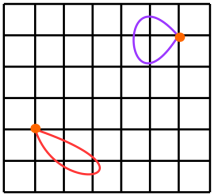
Excited states:
Multi-exponential fit forms:
Stability of fits!



Computing correlation functions: mesons

$$
\begin{aligned}
C(t) &= \langle 0|[\bar{\psi}\gamma_5\psi](x,t)[\bar{\psi}\gamma_5\psi](0,0)|0\rangle \\
&= \int DU\ tr[\gamma_5\ M^{-1}_{xt,00}\ \gamma_5\ M^{-1}_{00,xt}]\ det(M)\ e^{-S_g[U]} \\
&\quad - \int DU\ tr[\gamma_5\ M^{-1}_{xt,xt}\ \gamma_5\ M^{-1}_{00,00}]\ det(M)\ e^{-S_g[U]}
\end{aligned}
$$





On the importance sampled ensemble this amounts to computing

$$
\frac{1}{N}\sum\ tr[\gamma_5\ M^{-1}_{xt,00}\ \gamma_5\ M^{-1}_{00,xt}] - \ tr[\gamma_5\ M^{-1}_{xt,xt}\ \gamma_5\ M^{-1}_{00,00}]
$$

The sum is over the ensemble [N: # configurations in the ensemble].

Computing correlation functions: baryons

$$C(t) = \langle 0|[b_{ijk} u^i d^j s^k](x,t)[\bar{b}_{pqr} \bar{u}^p \bar{d}^q \bar{s}^r](0,0)|0\rangle$$
$$= \int DU \; b_{ijk} \; \bar{b}_{pqr} (U^{-1})^{ip}_{xt,00} (D^{-1})^{jq}_{xt,00} (S^{-1})^{kr}_{xt,00} \; det(M) \; e^{-S_g[U]}$$

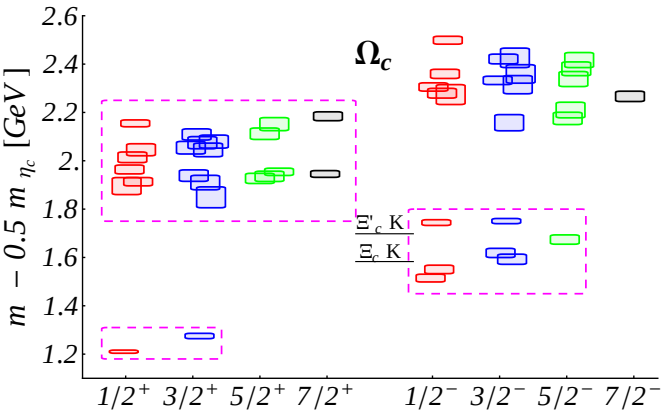
where b_{ijk} and $\bar{b}_{pqr}$ carries the color and spin structure of the operator.

On the importance sampled ensemble this amounts to computing

$$\frac{1}{N} \sum \; b_{ijk} \; \bar{b}_{pqr} (U^{-1})^{ip}_{xt,00} (D^{-1})^{jq}_{xt,00} (S^{-1})^{kr}_{xt,00}$$

The sum is over the ensemble [N: # configurations in the ensemble].

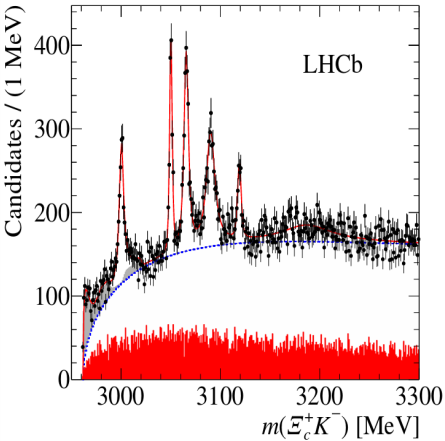
Baryons : Ω_c spectrum



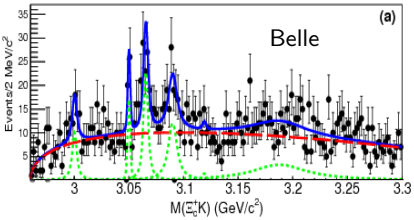
Magenta ellipses : States with strong non-relativistic content.

The low lying spectrum same as non-relativistic expectations.

LHCb discovery of excited Ω_c^0 baryons



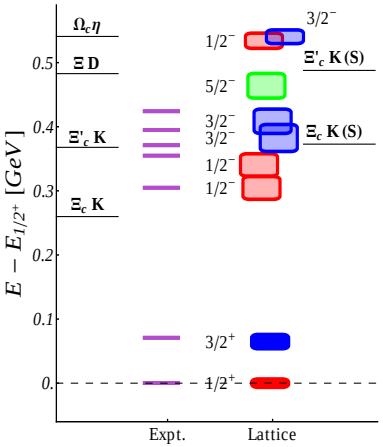
Resonance	Energy	Width	Q.no.
Ω_c^0	2695(2)	-	$1/2^+$
$\Omega_c^0(2770)$	2766(2)	-	$3/2^+$
$\Omega_c^0(3000)$	3000(1)	4.5(1)	?
$\Omega_c^0(3050)$	3050(1)	1(-)	?
$\Omega_c^0(3066)$	3066(1)	3.5(-)	?
$\Omega_c^0(3090)$	3090(1)	8.7(1)	?
$\Omega_c^0(3119)$	3119(1)	1(1)	?



Aaij *et al.* (LHCb) PRL**118** 182001 '17

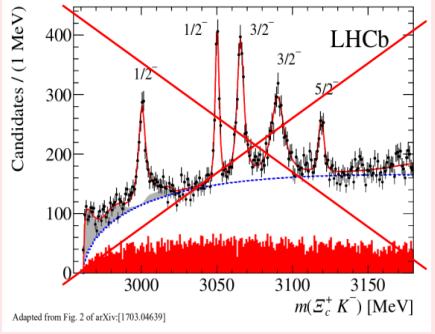
Confirmation by Belle : Yelton *et al.* (Belle) PRD**97** 051102 '18

Excited states, quantum number assignment and falsification



MP and Mathur 2017 PRL and other pheno predictions.

Excluded by 3.6σ



to be revisited!

LHCb PRD 104, L091102 (2021)

On the lattice, strong decays are ignored, and there remain various unattended systematics.

Computational requirements: a major bottleneck.

See my talk at ICNFP 2024 for more: click here.

Scattering in a finite volume

Topic for dedicated lectures.

Stable hadrons and resonances from lattice

Lectures by Prof. Sasa Prelovsek, University of Ljubljana: click here

Heavy Quark Symmetries, Effective Field theories [NEXT WEEK]

Lectures by Prof. Feng-Kun Guo, ITP CAS Beijing: click here

Thank you