Baryon masses from an effective field theory

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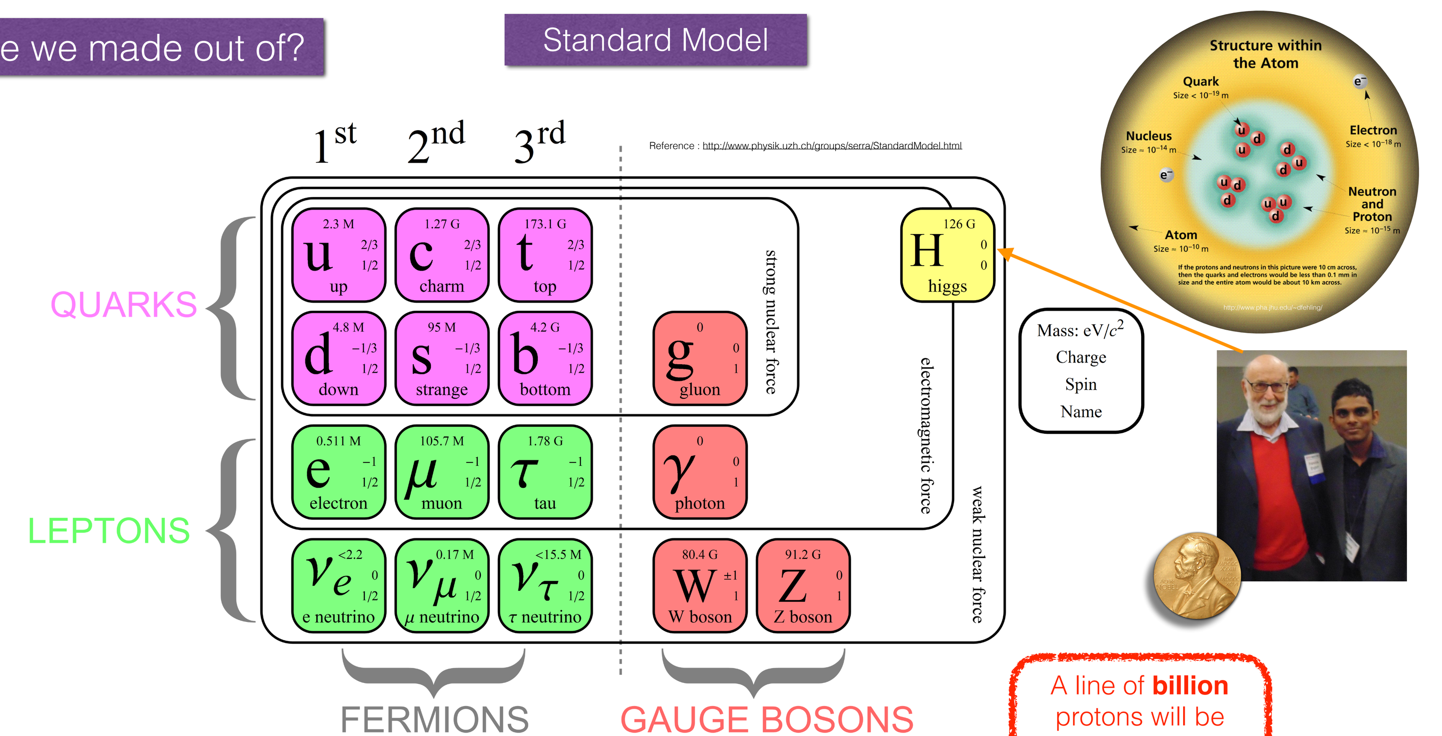
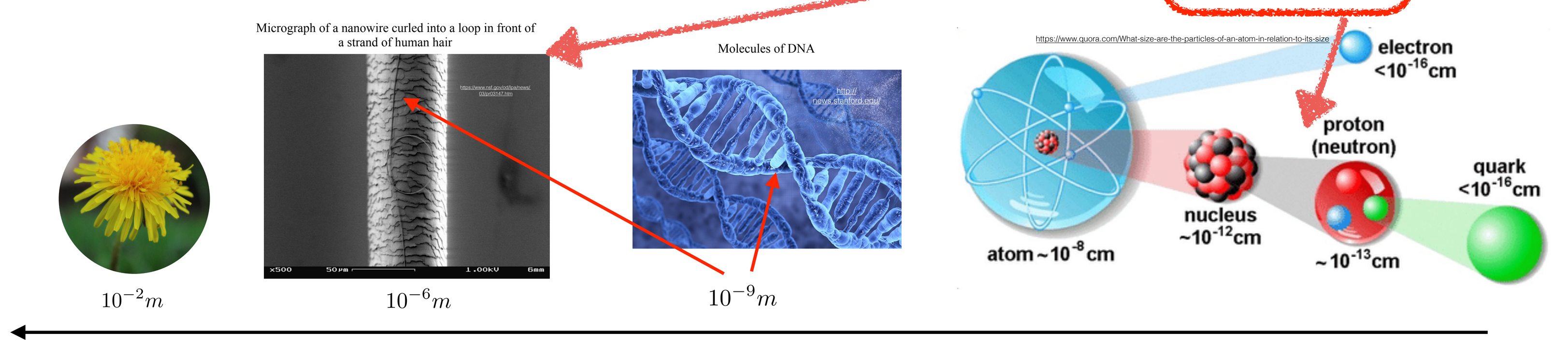
HAMPTON UNIVERSITY — THE STANDARD OF EXCELLENCE

What are we made out of?

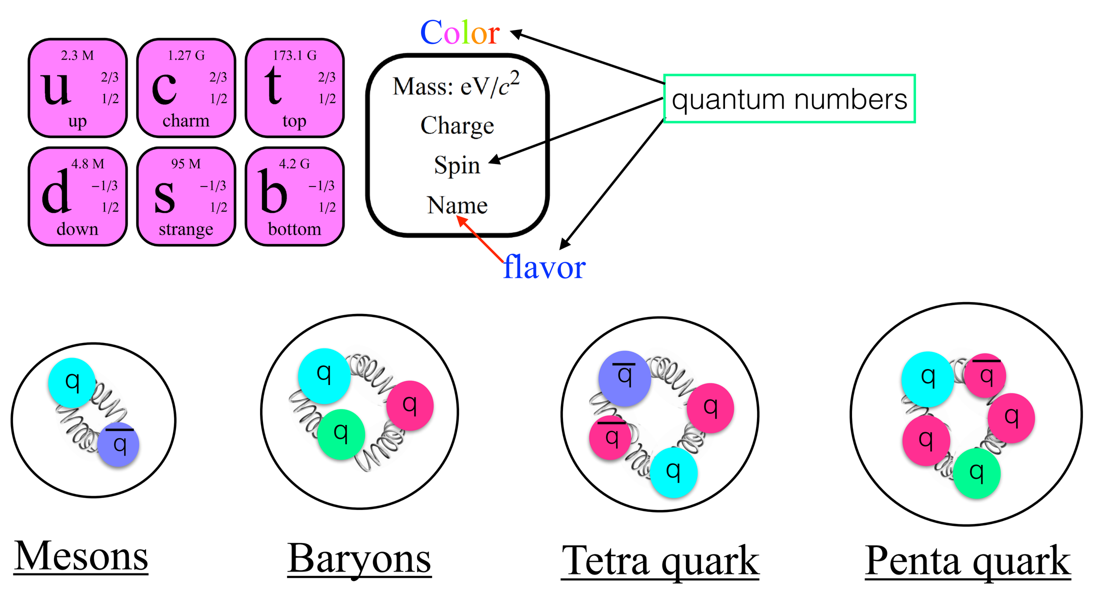
Standard Model



How small are they?



So, what kinds of quark combinations exist in "Nature"

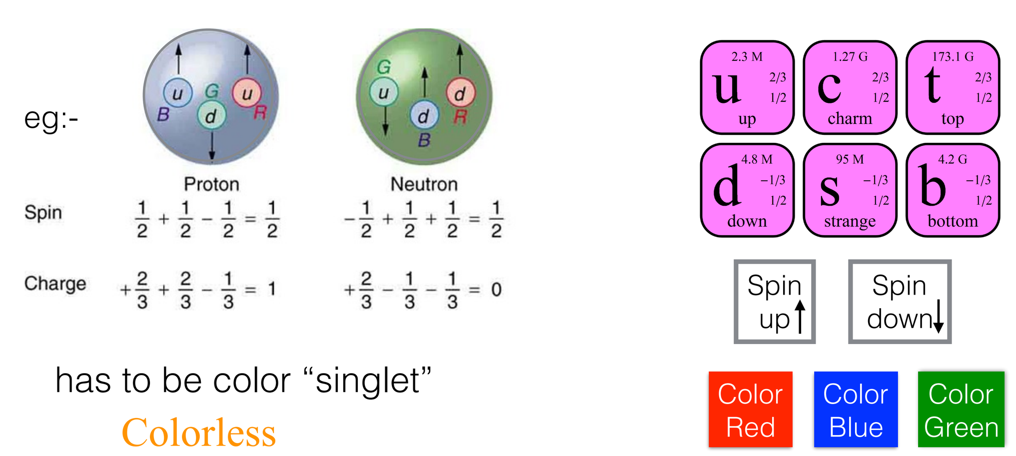


Baryons

What is a "Baryon" or "Baryon State"?

A configuration of quarks which consists of 3 quarks

Let's build some baryons



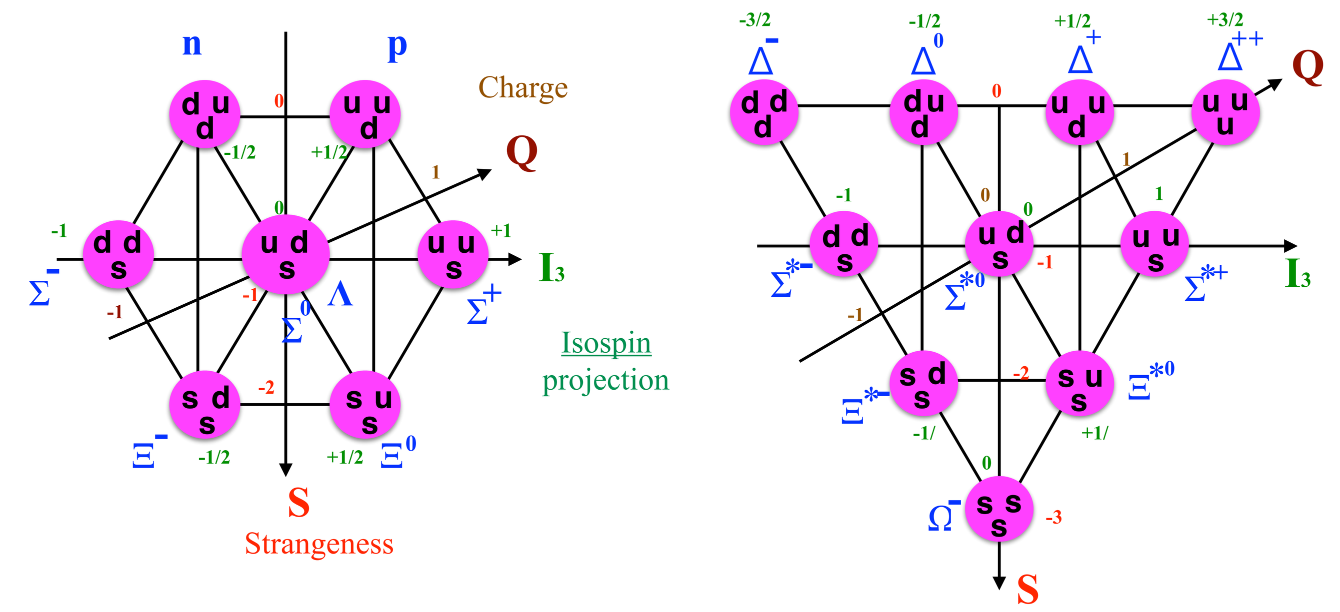
has to be color "singlet"

Colorless

Ground state Baryons

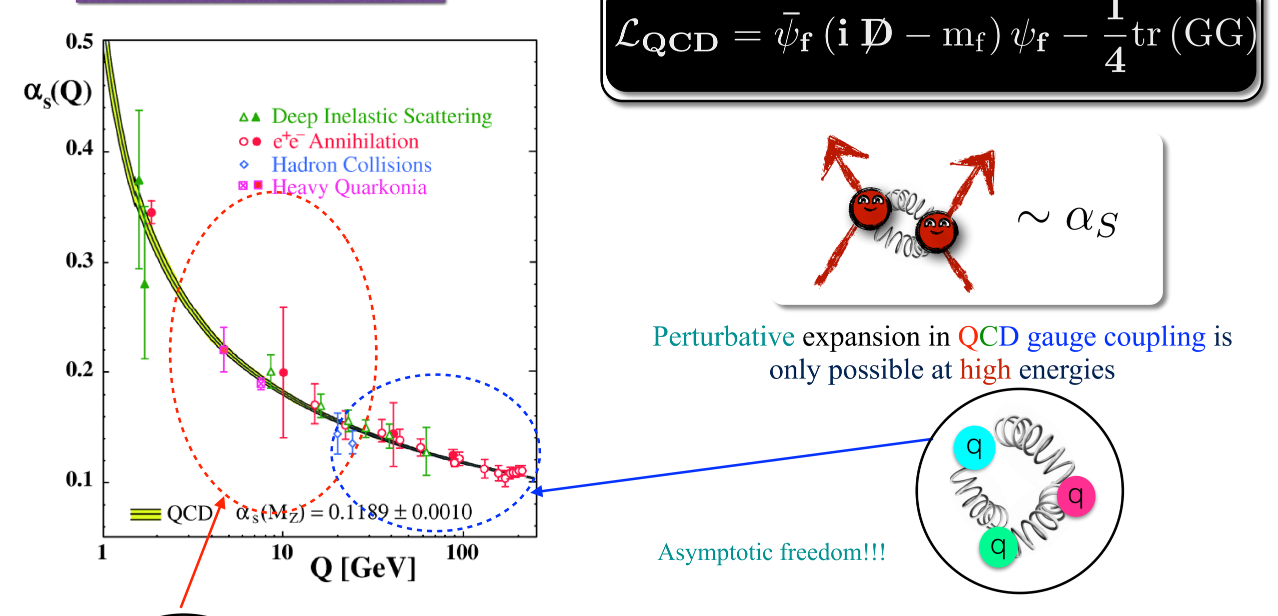
When the configuration of three quarks have minimum energy, we call it "ground state"

We need more quantum numbers (labels which can have certain values) to specify baryon states



Behavior of Quarks

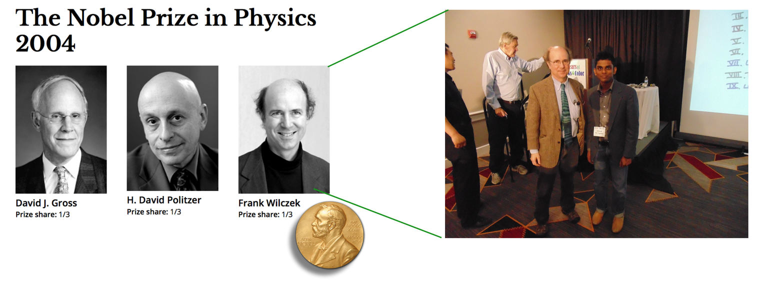
$$\mathcal{L}_{\rm QCD} = \bar{\psi}_{\rm f}\,(\mathrm{i}\,\not{D} - \mathrm{m_f})\,\psi_{\rm f} - \frac{1}{4}\mathrm{tr}\,(GG)$$



Perturbative expansion in QCD gauge coupling is only possible at high energies

Asymptotic freedom!!!

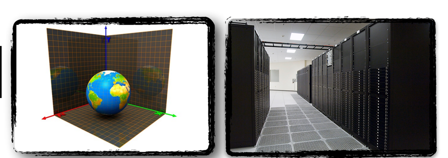
The Nobel Prize in Physics 2004



So, how do we solve this?

$$\mathcal{L}_{\rm QCD} = \bar{\psi}_{\rm f}\,(\mathrm{i}\,\not{D} - \mathrm{m_f})\,\psi_{\rm f} - \frac{1}{4}\mathrm{tr}\,(GG)$$

Effective Theories ← Lattice QCD



Virginia's biggest and fastest supercomputer @Jefferson Lab

- ChPT: $\frac{p}{\Lambda_{QCD}}$ & $\frac{m_q}{\Lambda_{QCD}}$
- $\frac{1}{N_c}$
- HQET: $\frac{\Lambda_{QCD}}{m_Q}$

All of them have their own expansion parameters

$$L(\text{Lagrangian}) = x^0 L_{LO} + x^1 L_{NLO} + x^2 L_{NNLO} + x^3 L_{NNNLO} + ...$$

Degree of freedom : Hadrons

Baryon Fields

$$L_B = B^\dagger\left(iD_0 + \mathring{g}_A u^{ia} G^{ia} - \frac{C_{HF}}{N_c}\vec{S}^2 - \frac{c_1}{2}N_c\chi_+\right)B$$

$$(\partial_0 - i\Gamma_0)$$

$$\left(\frac{1}{2}\left(u^\dagger(i\partial_0 + r_0)u + u(i\partial_0 + l_0)u^\dagger\right)\right)$$

$$Tr\langle\left(u^\dagger(i\partial_i + r_i)u - u(i\partial_i + l_i)u^\dagger\right)\lambda^a\rangle G^{ia}$$

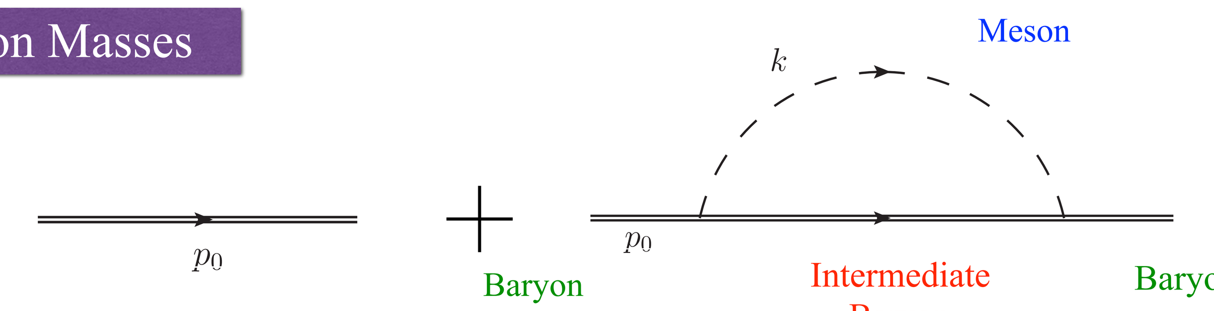
Meson Fields

$$u = exp(\frac{i\Pi}{2F_\pi})$$

$$1/N_c = \mathcal{O}(p) = \mathcal{O}(\xi)$$

$$L_B(\xi), L_B(\xi^2), L_B(\xi^3)$$

Baryon Masses



$$M_B = \frac{1}{\xi}N_c M_0 + \xi\frac{C_{HF}}{N_c}\hat{S}^2 + \xi\frac{C_1}{2}N_c\chi_+^0 + \left(\frac{\delta\Sigma^F - \xi^2\left[\mu_1\tilde{\chi}_+ + \delta\mu_1\tilde{\chi}_+ + \frac{\delta C_{HF}}{N_c^2}\hat{S}^2 + \frac{\delta C_1}{2}\chi_+^0\right] - \xi^3\left[\frac{\mu_2^0}{N_c}\chi_+^0\hat{S}^2 + \frac{\mu_2}{N_c}\tilde{\chi}_+\hat{S}^2 + \frac{\mu_3}{N_c}\tilde{\chi}_+^a S^i G^{ia}\right]}{1 - \xi\delta Z^F + \xi\left(\frac{w_1}{N_c} + \frac{w_2}{N_c}\hat{S}^2 + z_0 N_c\chi_+^0\right)}\right)$$

Where, $\delta Z = \frac{\partial}{\partial \mathfrak{p}^0}\delta\Sigma$

Mapping the coefficients with their **natural sizes** (in MeV),

M_0	C_{HF}	C_1	μ_1	$\delta\mu_1$	δC_{HF}	δC_1	w_1	w_2	z_0	μ_2^0	μ_2	μ_3
c[1]	c[2]	c[4]	c[3]	c[5]	c[6]	c[7]	c[8]	c[9]	c[10]	c[11]	c[12]	c[13]
300	300	0.002	0.002	0.002	0.002	0.002	1	1	4×10^{-6}	0.002	0.002	0.002

Gell-Mann-Okubo (GMO) Relation

$$(3M_\Lambda + M_\Sigma) - (M_N + M_\Xi) = 0$$

Equal Spacing (ES) Relation

$$M_{\Sigma^*} - M_\Delta = M_{\Xi^*} - M_{\Sigma^*} = M_\Omega - M_{\Xi^*}$$

Preliminary Results

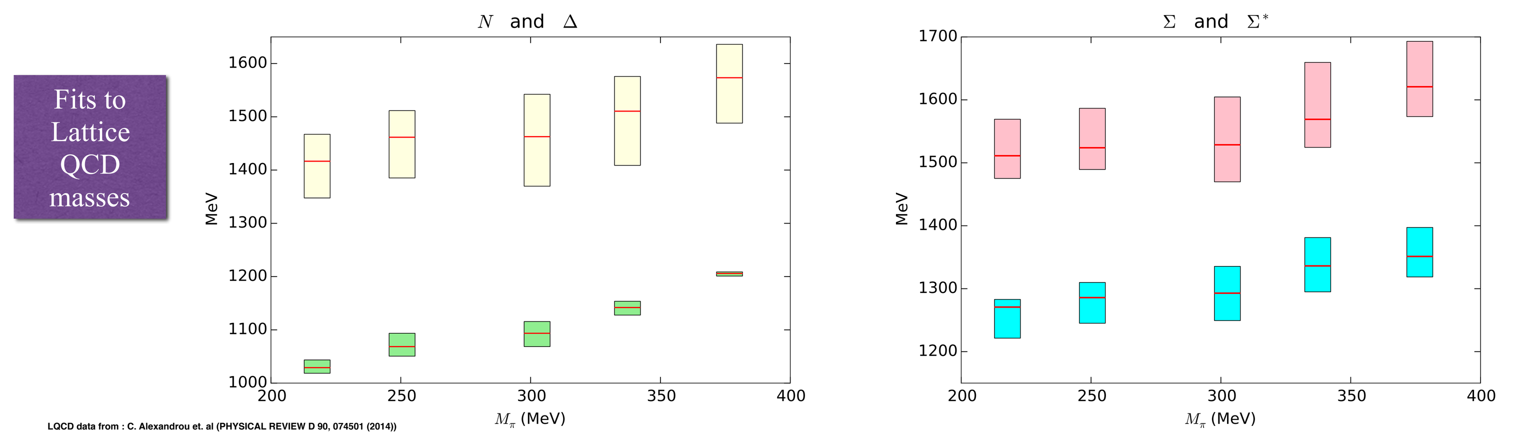
M_0	C_{HF}	C_1	μ_1	$\delta\mu_1$	δC_{HF}	δC_1	w_1	w_2	z_0	μ_2^0	μ_2	μ_3
c[1]	c[2]	c[4]	c[3]	c[5]	c[6]	c[7]	c[8]	c[9]	c[10]	c[11]	c[12]	c[13]
300	300	0.002	0.002	0.002	0.002	0.002	1	1	4×10^{-6}	0.002	0.002	0.002
318.87	**247.03**	**0**	**0.00015**	**0**	**0**	**-0.00083**	**0**	**-1.85**	$\mathbf{6.35\times10^{-6}}$	**-0.0018**	**-0.00089**	**-0.00029**

Fitted masses with partial contributions

$\chi^2 = 31.89$, **Pion mass = 139 Mev, Kaon Mass = 250 MeV**

Baryon	Mass [MeV]	Fitted Mass [MeV]	$\delta\Sigma^F$	$\delta\Sigma^F + ct.$	$Ct_{\delta\Sigma}$	δZ^F	$\delta Z^F + ct.$	$Ct_{\delta Z}$
N	938	931.35	-3.21	61.09	64.30	-0.96	0.40	1.36
Λ	1116	1126.05	-80.05	22.46	102.51	-0.77	0.59	1.36
Σ	1189	1192.32	-168.80	-100.79	68.01	-0.76	0.59	1.36
Ξ	1315	1308.27	-202.64	-79.16	123.47	-0.58	0.78	1.36
Δ	1228 - 50i	1227.25 - 44.93i	-72.80 - 30.33i	-18.26 - 30.33i	54.54	0.10 - 0.54i	-0.38 - 0.54i	-0.48
Σ^*	1383 - 18i	1384.92 - 24.13i	-90.94 - 25.27i	174.17 - 25.27i	265.11	0.37 - 0.45i	-0.11 - 0.45i	-0.48
Ξ^*	1532 - 5i	1530.4 - 4.75i	-109.48 - 15.16i	366.20 - 15.16i	475.69	0.53 - 0.27i	0.05 - 0.27i	-0.48
Ω	1672	1672.43	-128.44	557.81	686.26	0.58	0.10	-0.48
GMO	31	91.23	2.74	2.74	0	0.005	0.005	0
ES1	155	157.67	-18.13	192.43	210.57	0.27	0.27	0
ES2	149	145.48	-18.54	192.02	210.57	0.16	0.16	0
ES3	140	142.02	-18.95	191.61	210.57	0.05	0.05	0
ES1-ES2	6	12.18	0.41	0.41	0	0.11	0.11	0
ES2-ES3	9	3.45	0.41	0.41	0	0.11	0.11	0

Fits to Lattice QCD masses



Acknowledgements

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