Meson spectroscopy and pion cloud effect on baryon masses

Stanislav Kubrak, Christian Fischer,
Helios Sanchis-Alepuz, Richard Williams

Justus-Liebig-University, Giessen

13.06.2014

Talk Objectives

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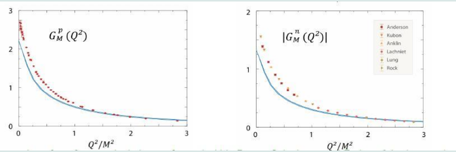
1. **Pion cloud effect on baryon masses**
2. Light meson spectroscopy for $J = 0..3$
3. Charmonium spectroscopy and gluon shape impact

Pion Cloud Effect - why it is crucial?

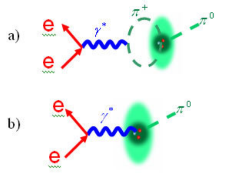
Evidence of pion clouds

- The excess of $\bar{u}_{sea}/\bar{d}_{sea} = 1.14$ in nucleon sea.
  P. Amaudruz at al, Phys. Rev. Lett. 66, 2712(1991)
- The ratio E2/M1 in Nucleon-Delta transition.
  K. Joo et al. (CLAS), Phys. Rev. Lett. 88, 122001 (2002), hep-ex/0110007.

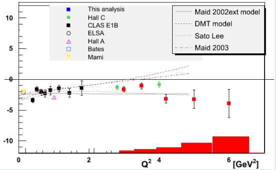
This effect is expect to impact the nucleon form factors behaviour:



G. Eichmann and C. Fischer,Eur.Phys.J.A48,9(2012)



a) The pion cloud probed at long wavelengths. b) The nucleon core probed at high Q2

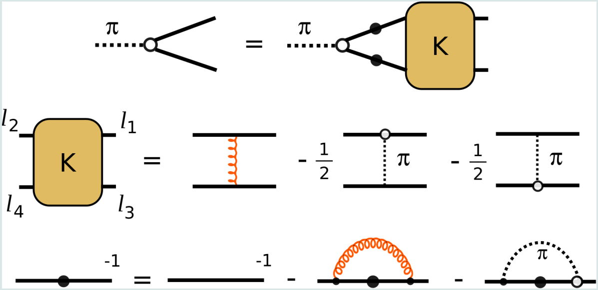


The ratio E2/M1 as a function of Q^2.

DSE and BSE with the pion cloud

There are familiar rainbow-ladder Dyson-Schwinger and Bethe-Salpeter equations, but with an additional pion exchange term:

System of DSEs and BSEs

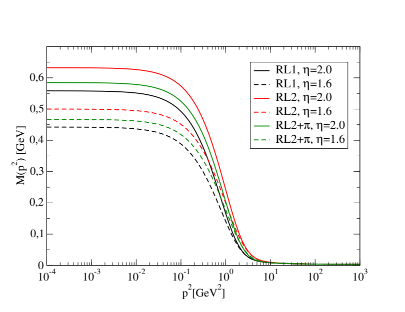


Christian S. Fischer, Richard Williams, Phys.Rev.D78:074006,2008

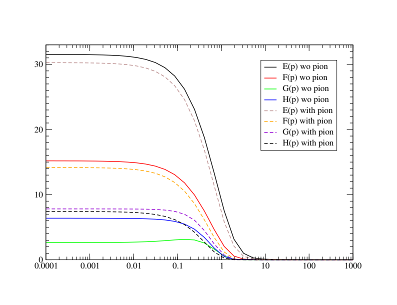
Internal quark-pion vertex: $\Gamma_\pi(p^2) = \dfrac{B(p^2)_{chiral}}{f_\pi}$

Pion cloud effect

Quark mass functions



Pion dressing functions

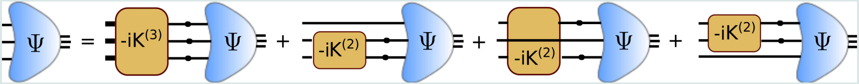


Properties

- Provides dynamical quark mass generation
- Fulfil Gell-Mann-Oakes-Renner relation
- Conserves Axial WTI

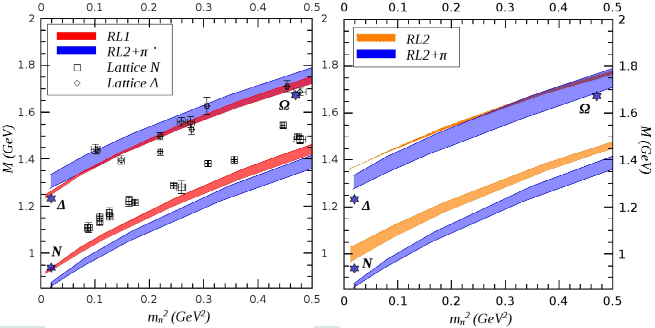
Fadeev equation for baryons

Fadeev Equation



Helios Sanchis-Alepuz, SK, Christian S. Fischer, PLB 733C (2014)

Evolution of Nucleon and Delta masses



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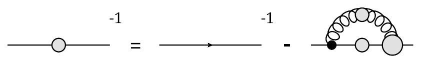
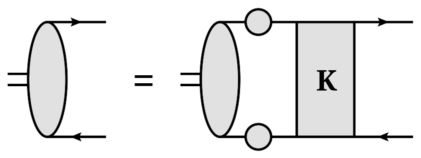
Rainbow-ladder truncation

Quark DSE



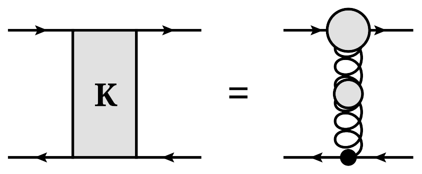
$$S^{-1}(p) = Z_2 S_0^{-1} + g^2 Z_{1f} C_F \int_k \gamma^\mu S(k) \Gamma^\nu(k,p) D_{\mu\nu}$$

Meson BSE



$$[\Gamma(p;P)]_{tu} = \lambda \int_k K^{(2)}_{rs;tu}(p,k;P)\, [\chi(k;P)]_{sr} \ .$$

Kernel as an effective one-gluon exchange



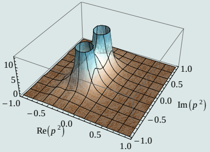
$$\alpha_{\text{eff}}(p^2) = \pi \frac{\eta^7}{\Lambda^2} p^2 e^{-p^2 \frac{\eta^2}{\Lambda^2}} + pQCD$$

$$\Lambda = 0.72\,GeV \ , \eta = 1.8 \pm 0.2$$

P. Maris, R. Tandy, PRC 78

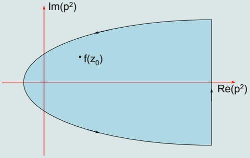
Devil is in details

Poles in quark propagator



$$\mathcal{C} = t^2 + i2tM_{BS} - M_{BS}^2$$

Cauchy Integral



$$f(z_0) = \frac{1}{2\pi i}\oint_{\mathcal{C}} \frac{dzf(z)}{z - z_0}$$

Eigenvalue extrapolation

Barycentric rational interpolation:

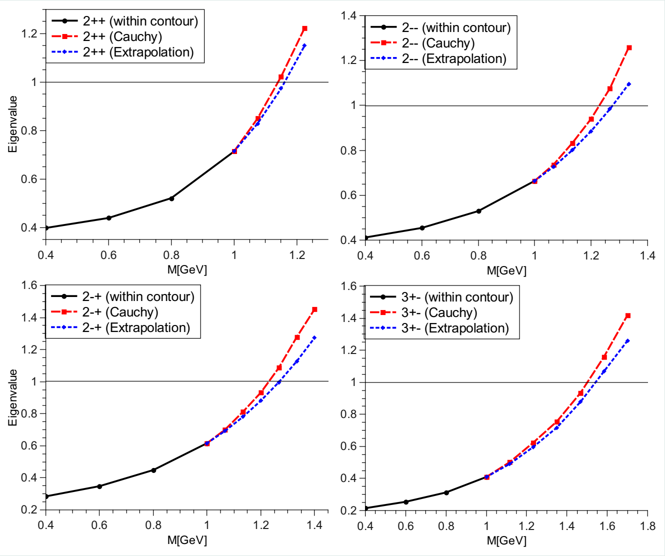
$$R(x) = \frac{\sum_{i=0}^{N-1} \frac{w_i}{x - x_i} y_i}{\sum_{i=0}^{N-1} \frac{w_i}{x - x_i}} ,$$

$$w_k = \sum_{i=k-d}^{k} (-1)^k \prod_{j=i, j\neq k}^{i+d} \frac{1}{x_k - x_j} .$$

J. Berrut, L. Trefethen, SIAM Rev 46

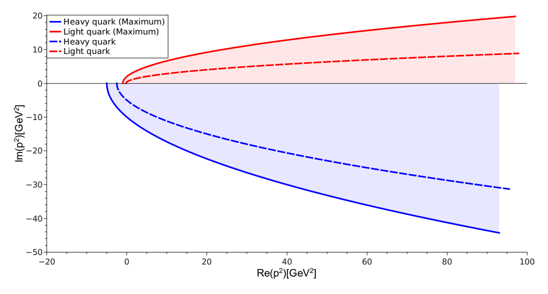
Comparison of extrapolations

Meson eigenvalue curves



Partitioning optimization

Heavy and light quark's contours



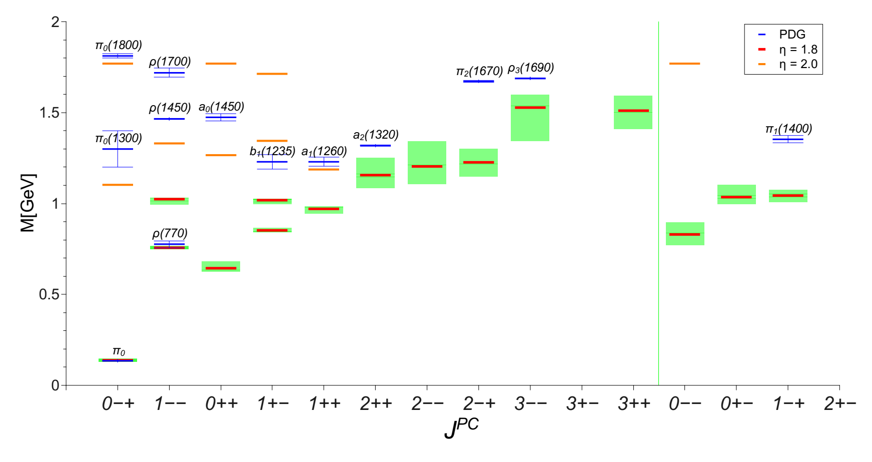
$$\mathcal{C}_{Heavyquark} = k + \zeta P_{BS}$$

$$\mathcal{C}_{Lightquark} = k + (1-\zeta) P_{BS}$$

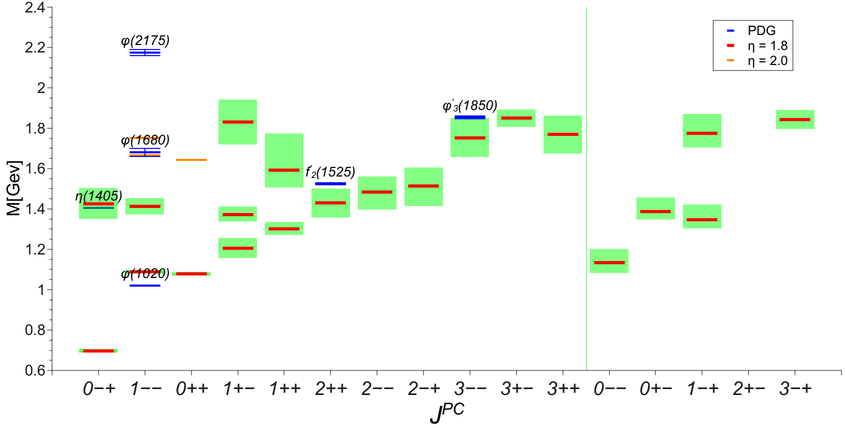
Optimal partitioning: $\zeta = \dfrac{1}{\sqrt{M^{max}_{heavy}/M^{max}_{light}} + 1}$

$n\bar{n}$ spectrum

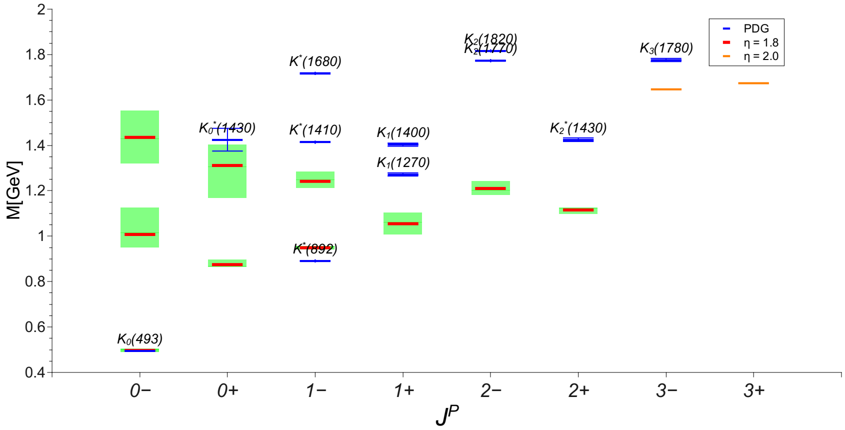
$n\bar{n}$ spectrum



$s\bar{s}$ spectrum

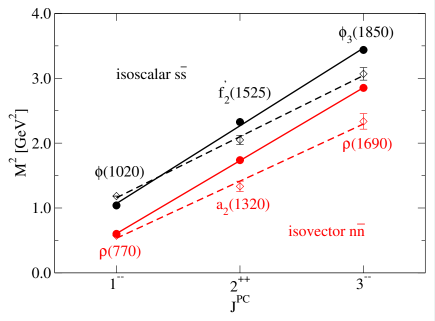


$n\bar{s}$ spectrum

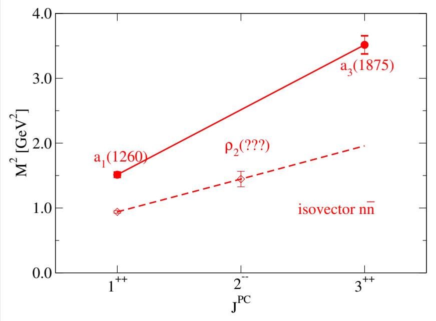


Regge trajectories

Natural parity

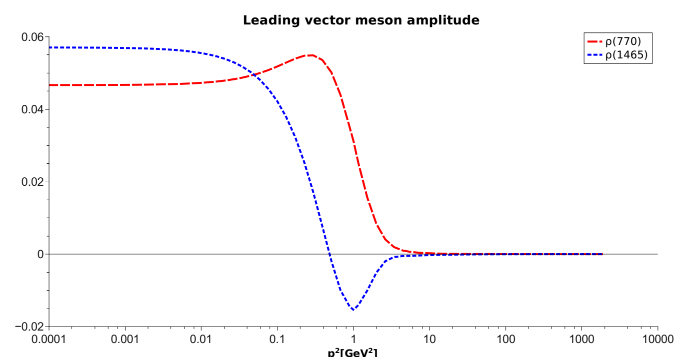


Unnatural parity



Radial excitations

Leading amplitudes for ground and excited states



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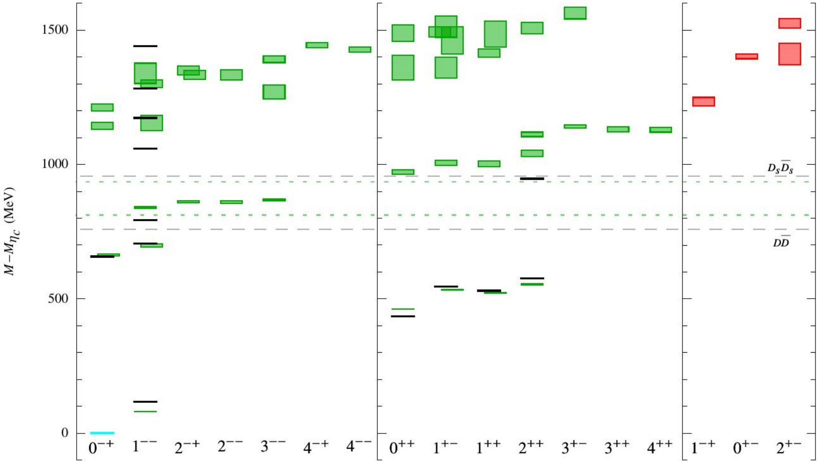
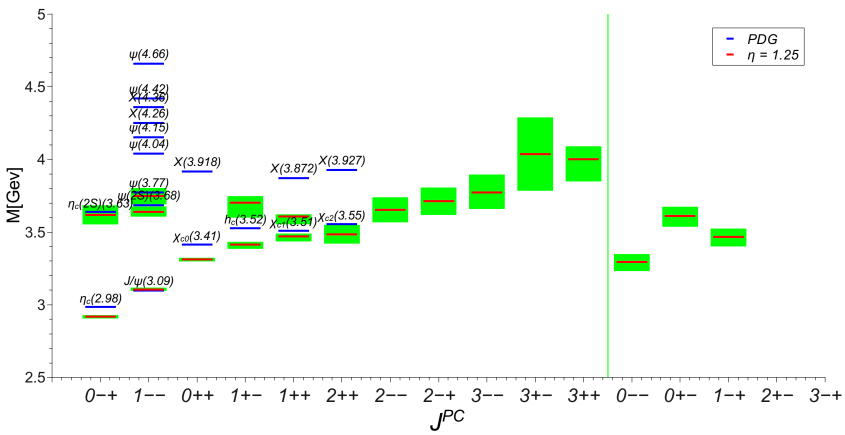
Lattice charmonium

Charmonium spectrum on the lattice



Liuming Liu et al., JHEP 07 (2012) 126

$c\bar{c}$ spectrum

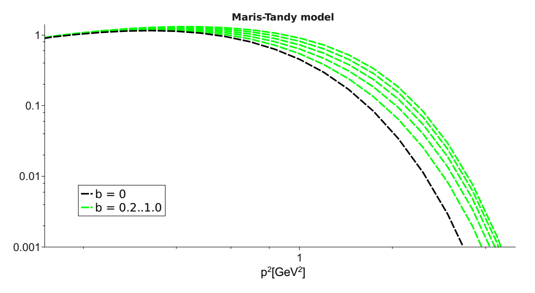


Gluon shape

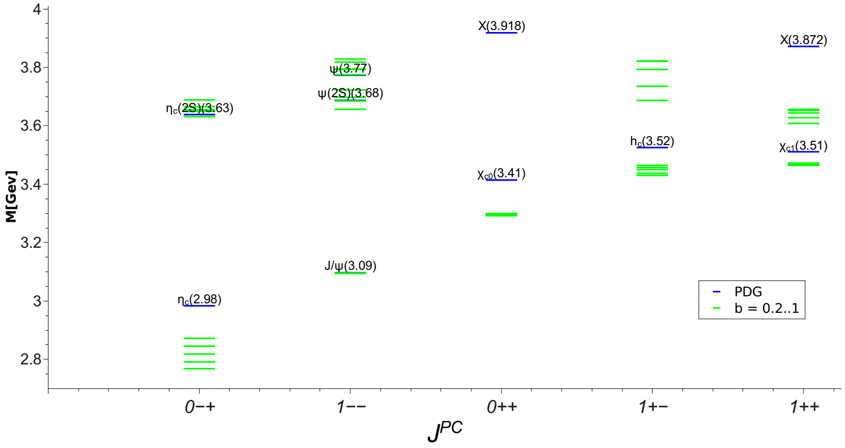
$$\alpha_{\text{eff}}(x^2) = \pi\eta^7 P_n(x^2) e^{-x^2\eta^2} + pQCD, \quad x^2 = \frac{p^2}{\Lambda^2}, \quad P_n(x^2) = \sum_{i=0}^{n} b_i x^{2i}$$

Particularly:

$$P_2(x^2) = x^2 + bx^4$$



Shape impact on the charmonium



Gradient descent

Cost function to re-gauge quark mass

$$\mathcal{J}(m_q) = \left(1 - \lambda_{J/\Psi}(M^{exp}_{J/\Psi})\right)^2$$

As example

$$P_2(x^2) = x^2 + bx^4$$

and $j = \Psi(2S), \Psi(3S)$

the fit gives: $b = 0.288$

Cost function to fit gluon shape parameters

$$\mathcal{J}(b_0, .., b_n) = \sum_j \left(1 - \lambda_j(M^{exp}_j)\right)^2$$

Use gradient descent to obtain b_i:

$$b_i = b_i - \frac{\partial \mathcal{J}(b_0, .., b_n)}{\partial b_i}$$

Further Development

- Increase a variability of the effective interaction (Scaling vs Decoupling)
- Charmonium weak decay constants
- Charm form factors and transition form factors
- Pion form factor with pion cloud effect

Conclusion

- $M_N - M_\Delta$ splitting and indication of missing self-gluon interaction
- $J = 3$ light meson spectrum
- Regge behaviour
- Similar pattern for $J = 2$ and $J = 3$ with the lattice in charmonium spectrum