Bethe-Salpeter Wave Functions of Hybrid Charmonia

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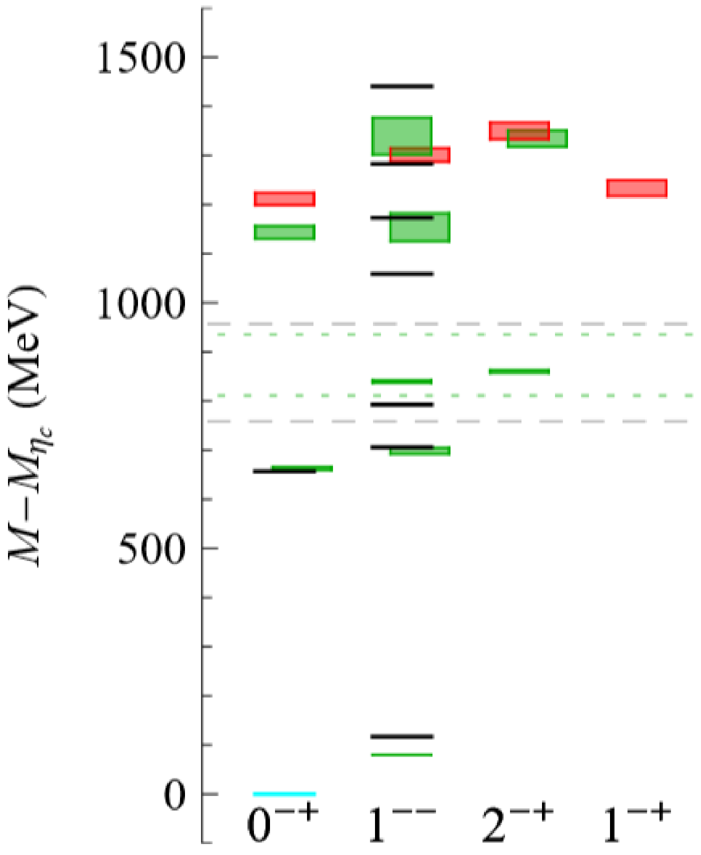
Implication of Hybrid Charmonia

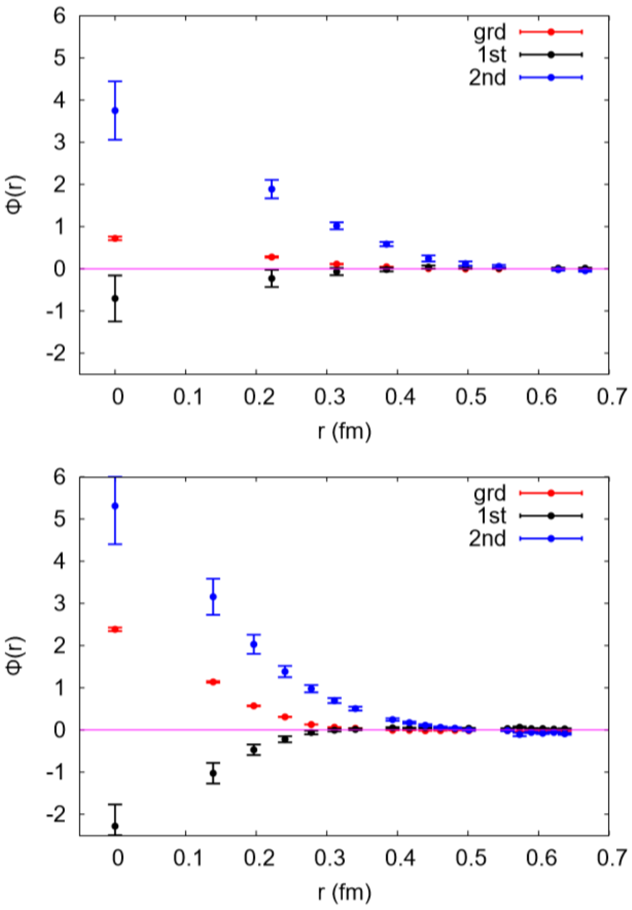
"Excited and exotic charmonium spectroscopy from lattice QCD",Liuming Liu et al. [arXiv:1204.5425v2[hep-ph]

--Four lightest hybrids as a supermultiplet in channel $1^{--},(0,1,2)^{-+}$.

"Exotic vector charmonium and its leptonic decay width", Ying Chen et al.[arXiv;1604.03401v1[hep-lat]

--Bethe-Salpeter Amplitude as a tool to recognize hybrid state out.





Basic Point of View

- A hybrid is a $\bar{c}c$ with a gluonic component
- Spin of $\bar{c}c$ in these four could be spin singlet and triplet, respectively
- Their masses are in near degenerate
- Hybrids are well-defined in quenched approximation
- Quenched gauge configurations used

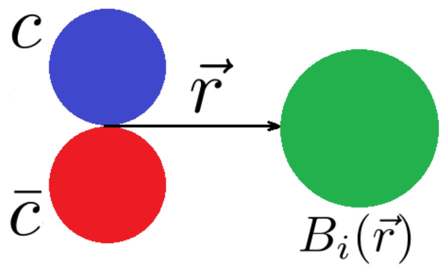
β	ξ	a_s	$La_s(fm)$	$L^3 \times T$	N_{conf}
2.4	5	0.222(2)(11)	3.55	$16^3 \times 160$	500
2.8	5	0.138(1)(7)	3.31	$24^3 \times 192$	200

- The configurations have been fixed into Coulomb gauge

Hybrid-like Operators & Bethe-Salpeter(BS) Wave Functions

- We construct a group of hybrid-like interpolating operators as

$$
\begin{aligned}
O_i^{(H1)}(\mathbf{x},t;\mathbf{r}) &= \bar{c}^a(\mathbf{x},t)\gamma_5 B_i^{ab}(\mathbf{x}+\mathbf{r},t)c^b(\mathbf{x},t), && 1^{--}\\
O_i^{(H2)}(\mathbf{x},t;\mathbf{r}) &= \bar{c}^a(\mathbf{x},t)\gamma_i B_i^{ab}(\mathbf{x}+\mathbf{r},t)c^b(\mathbf{x},t), && 0^{-+}\\
O_i^{(H3)}(\mathbf{x},t;\mathbf{r}) &= \bar{c}^a(\mathbf{x},t)\varepsilon_{ijk}\gamma_j B_k^{ab}(\mathbf{x}+\mathbf{r},t)c^b(\mathbf{x},t), && 1^{-+}\\
O_i^{(H4)}(\mathbf{x},t;\mathbf{r}) &= \bar{c}^a(\mathbf{x},t)|\varepsilon_{ijk}|\gamma_j B_k^{ab}(\mathbf{x}+\mathbf{r},t)c^b(\mathbf{x},t). && 2^{-+}
\end{aligned}
$$



$\bar{c}c$ *in spin singlet*
1^{--}
$\bar{c}c$ *in spin triplet*
$(0,1,2)^{-+}$

$\mathbf{r}$ is the displacement between $\bar{c}c$ and gluon(represented by chromomagnetic field B_i^{ab})

- The Bethe-Salpeter amplitude is defined as $\langle 0|O^H(r)\,|H\rangle$

Data Analysis Strategy

- The real two-point correlation functions we calculated

$$C(r,t) = \langle 0|O^H(r,t)O^W(\tau)\,|0\rangle$$

- Simultaneous fitting with many $C(r,t)$ under multi-exponential model, r corresponds to different separation displacement

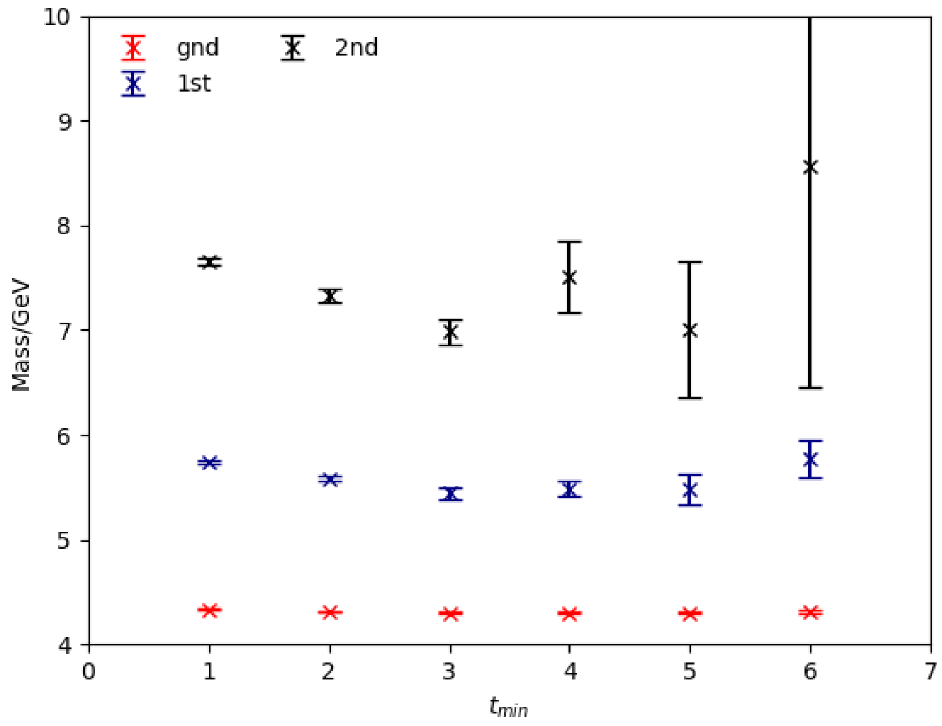
$$C(r,t) = \sum_i \Phi_i(r)\exp\{-m_i t\}$$

$\Phi_i(r)$ is proportional to BS wave functions.

- Fit window is

$$t \in [t_{min}, t_{max}]$$

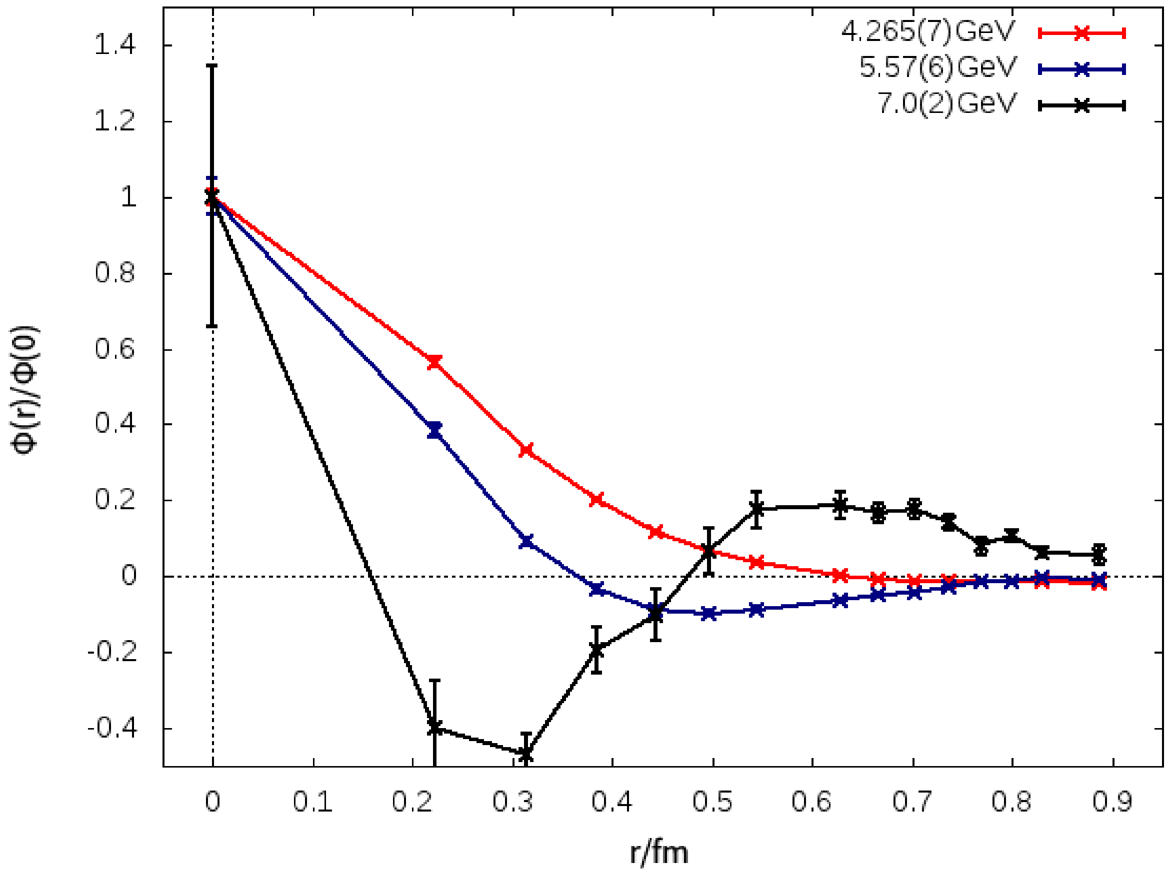
Shift t_{min} with t_{max} fixed to find a stable region.



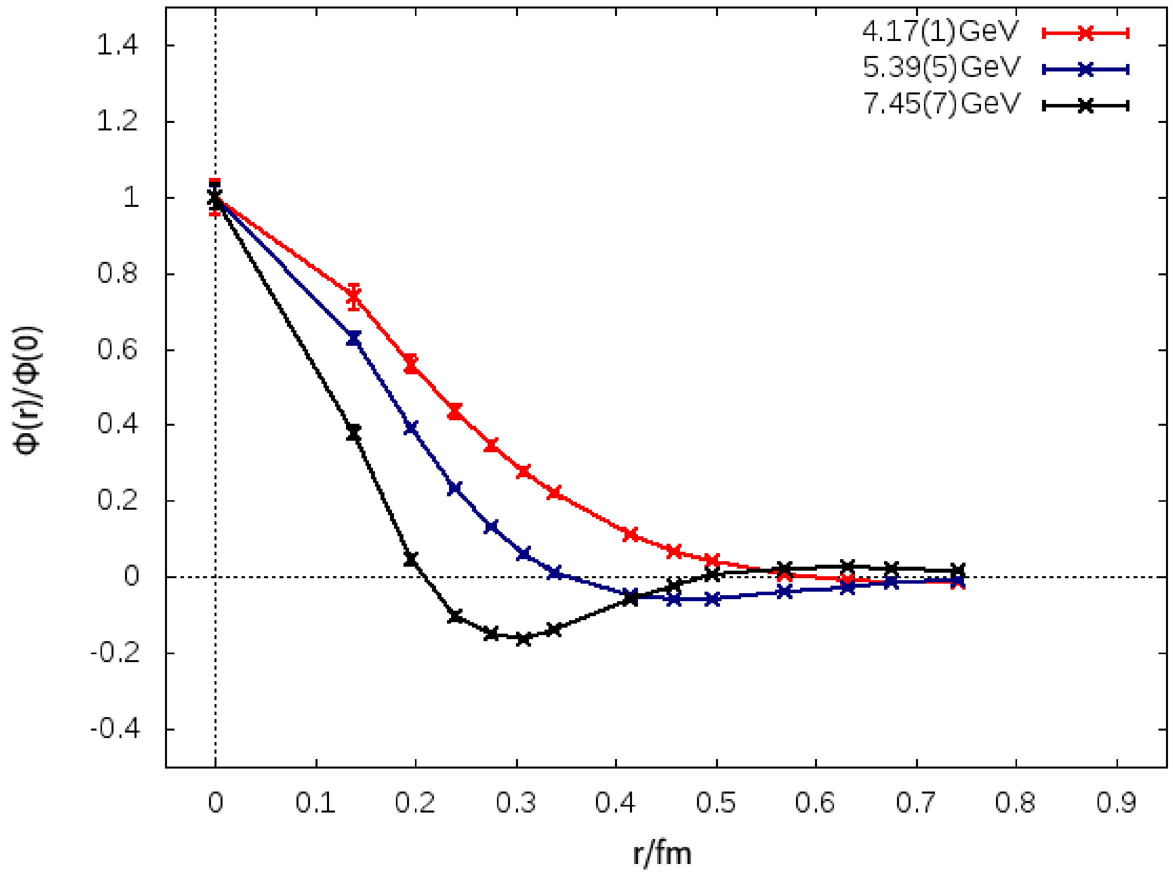
Exam. $1^{-+}, \beta = 2.4$

Exotic Channel 1^{-+}

$\beta = 2.4$

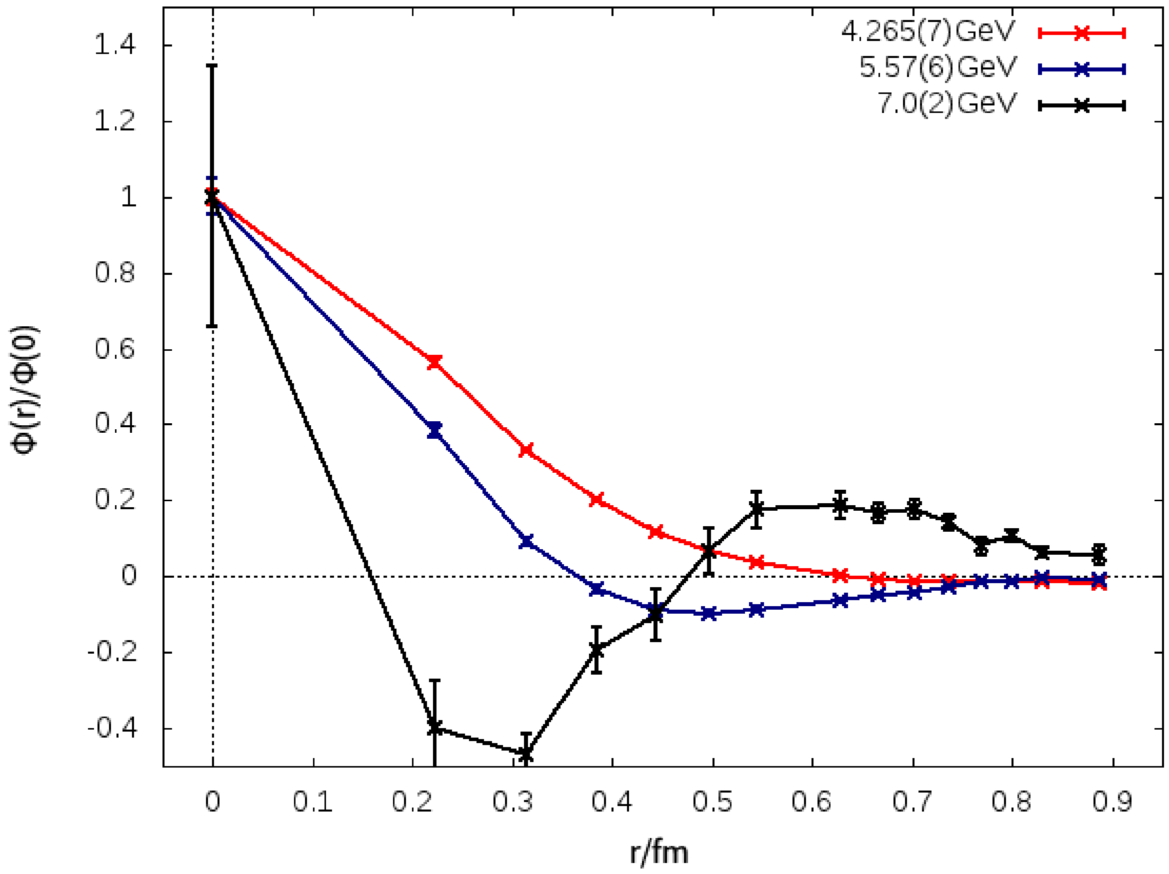


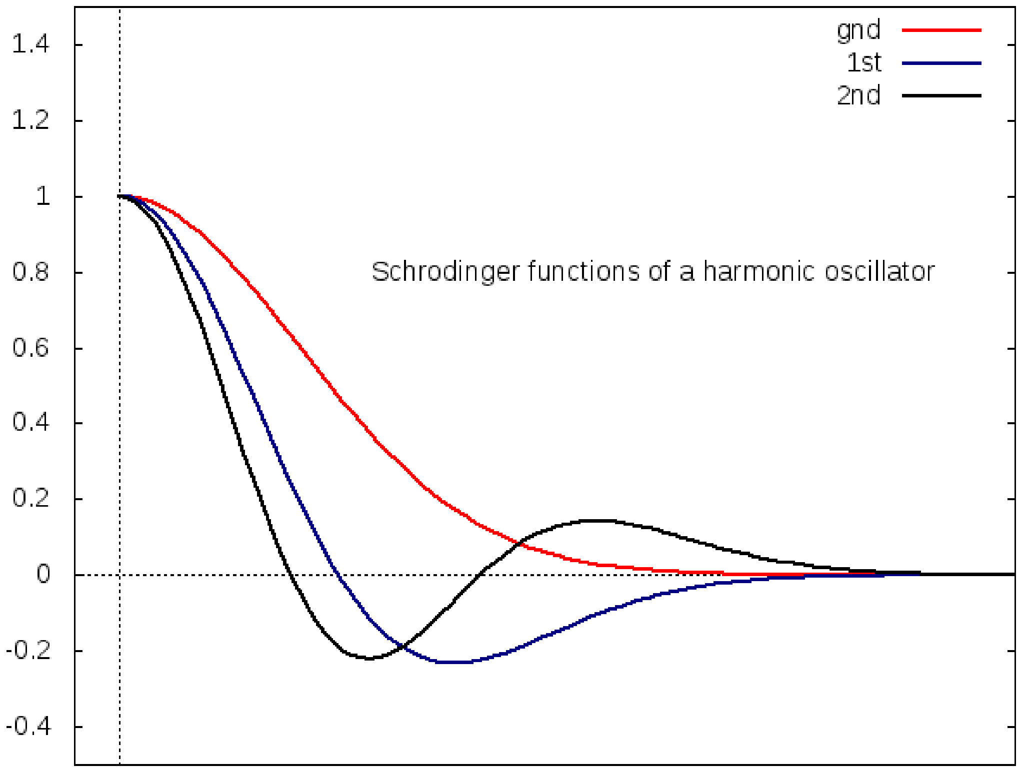
$\beta = 2.8$



Compare to Shrodinger Functions of A Harmonic Oscillator

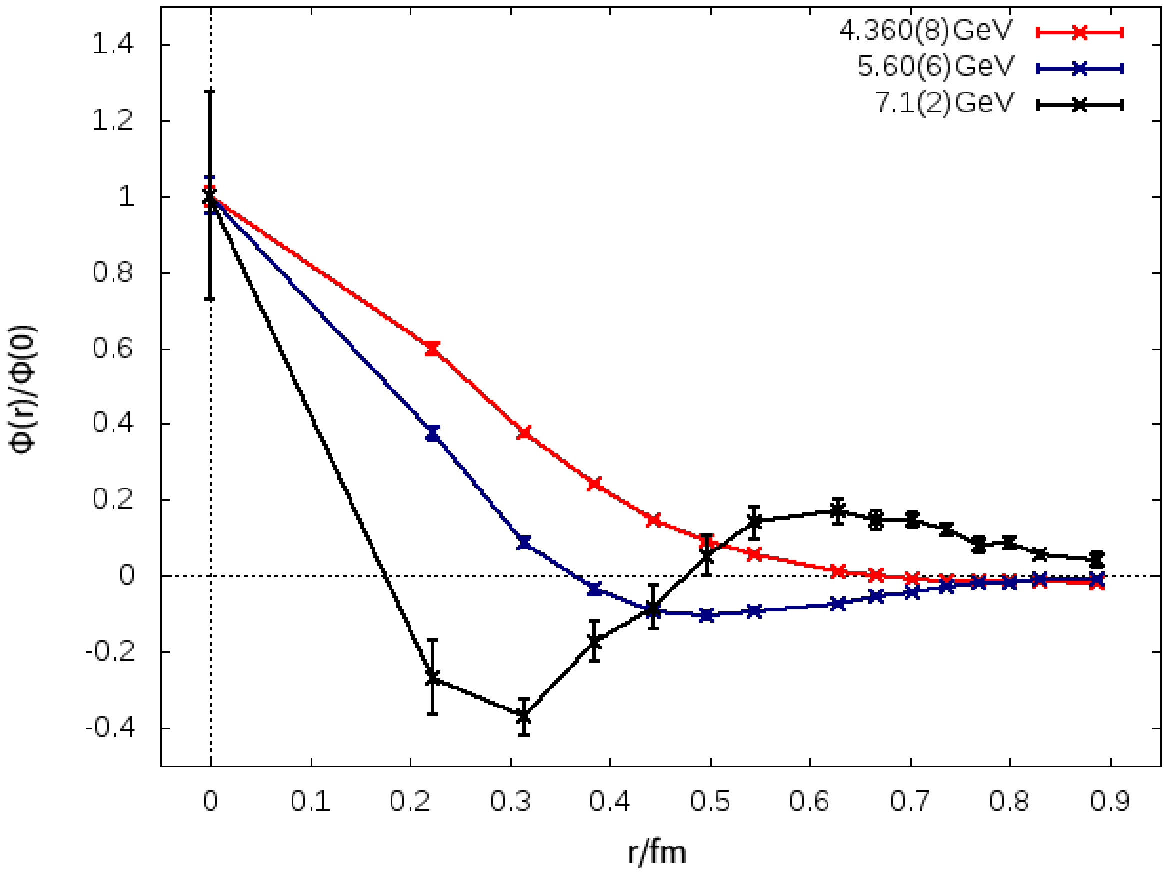
$\beta = 2.4$



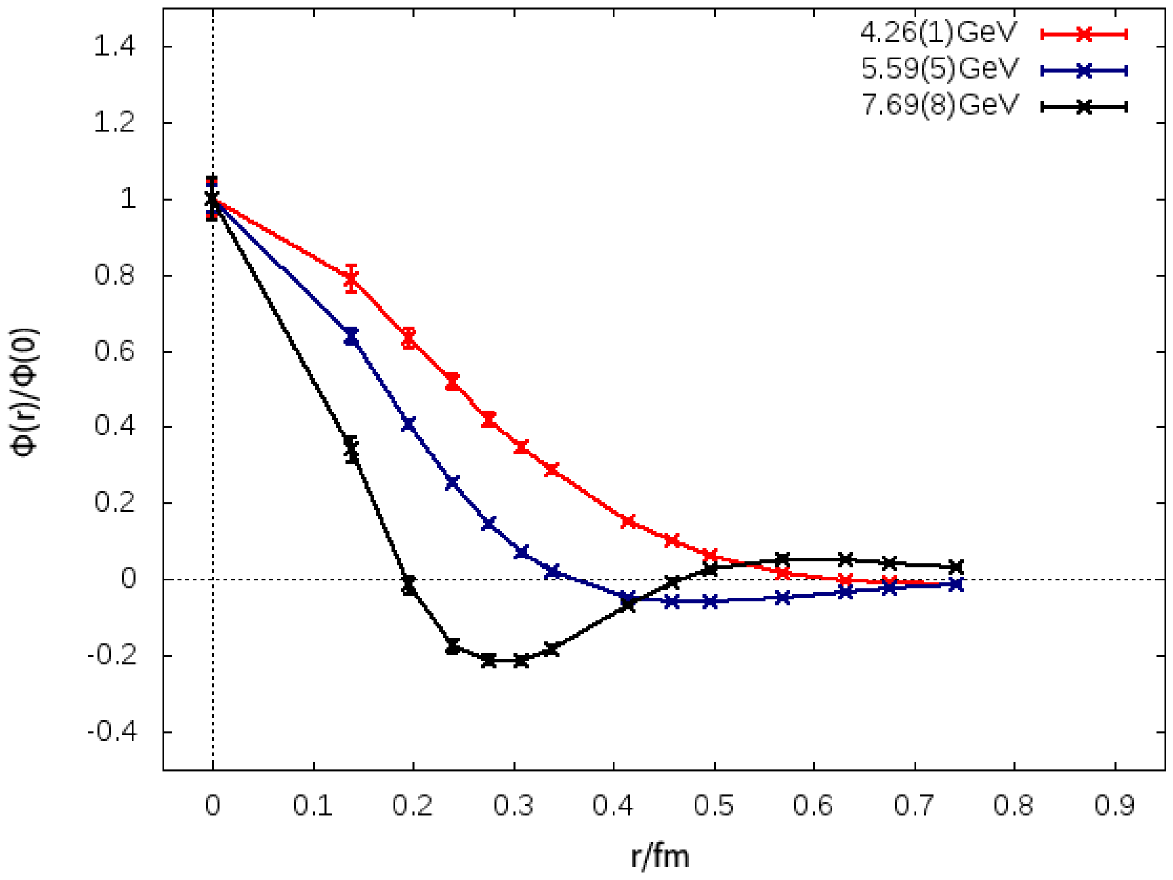


2^{-+}

$\beta = 2.4$



$\beta = 2.8$

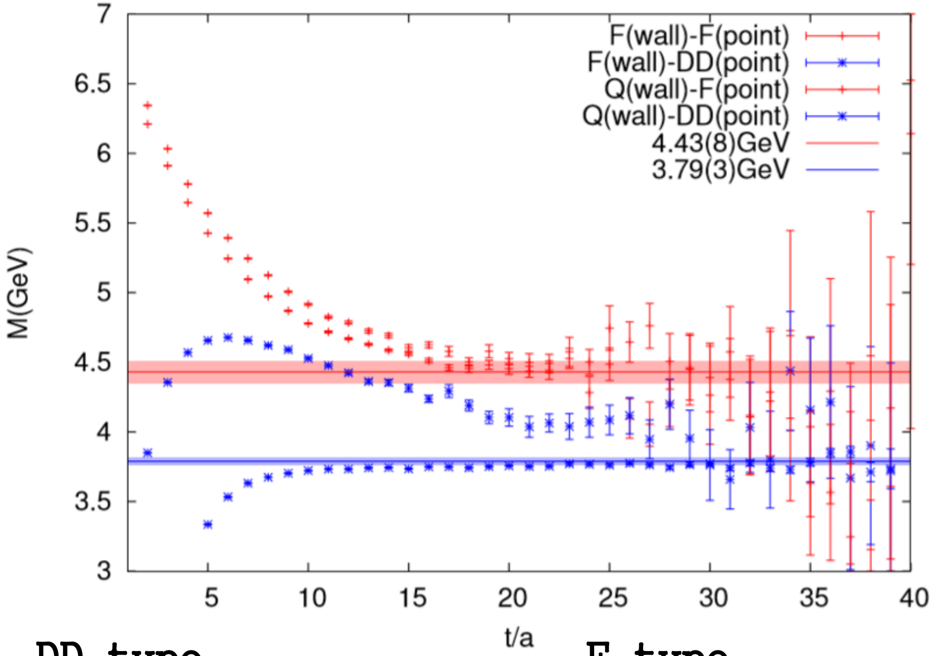


Why no conventional 2^{-+} states found ?

According to

"Lattice study on η_{c2} and X(3872)"(Y.B.Yang et al. PhysRevD.87.014501[arXiv:1206.2086 [hep-lat]]),

a $q\bar{q}B$ type(F-type, red dots in figure) operator hardly couples to conventional states like $\eta_{c2}(2^{-+})$, instead, it couples to a state around 4.43GeV mostly (which we treat as a ground state of hybrids here).



DD-type

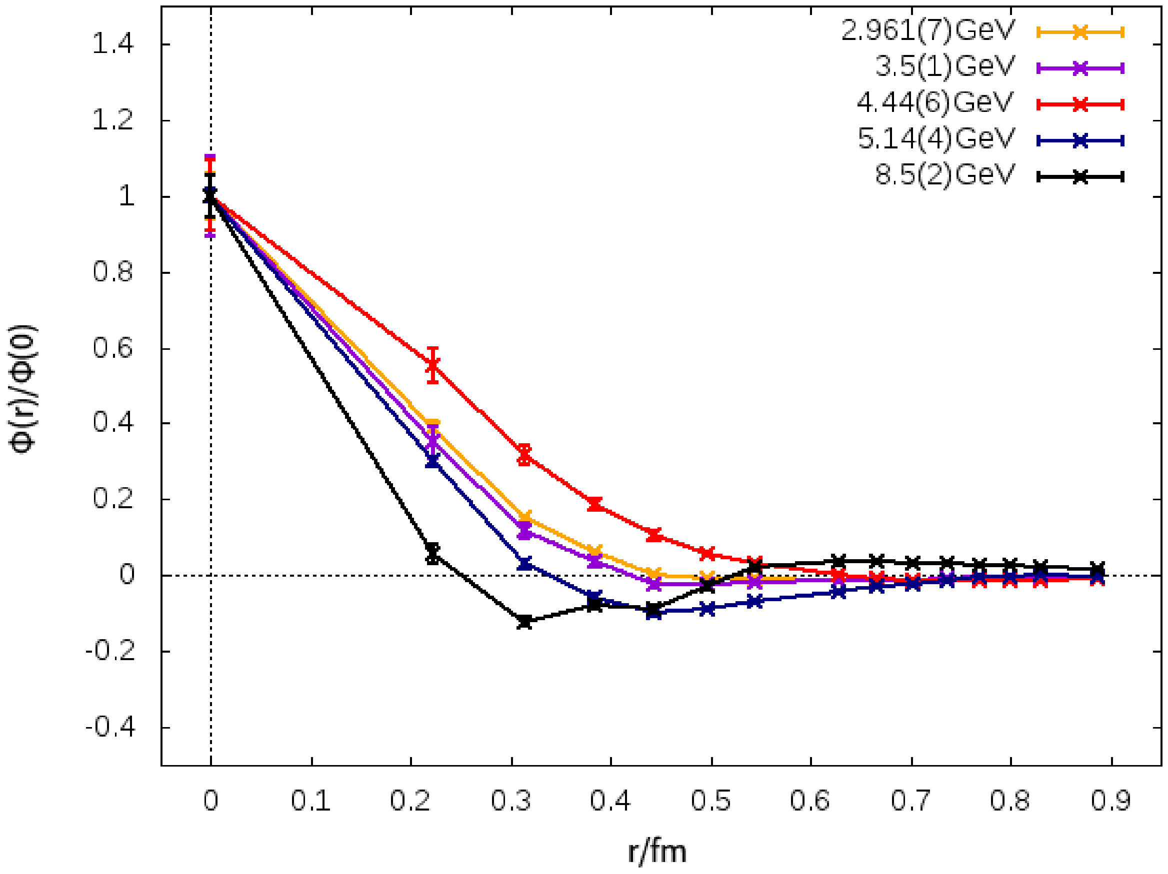
$|\epsilon_{ijk}|\bar{q}\gamma_5\overleftrightarrow{D}_i\overleftrightarrow{D}_j q$

F-type

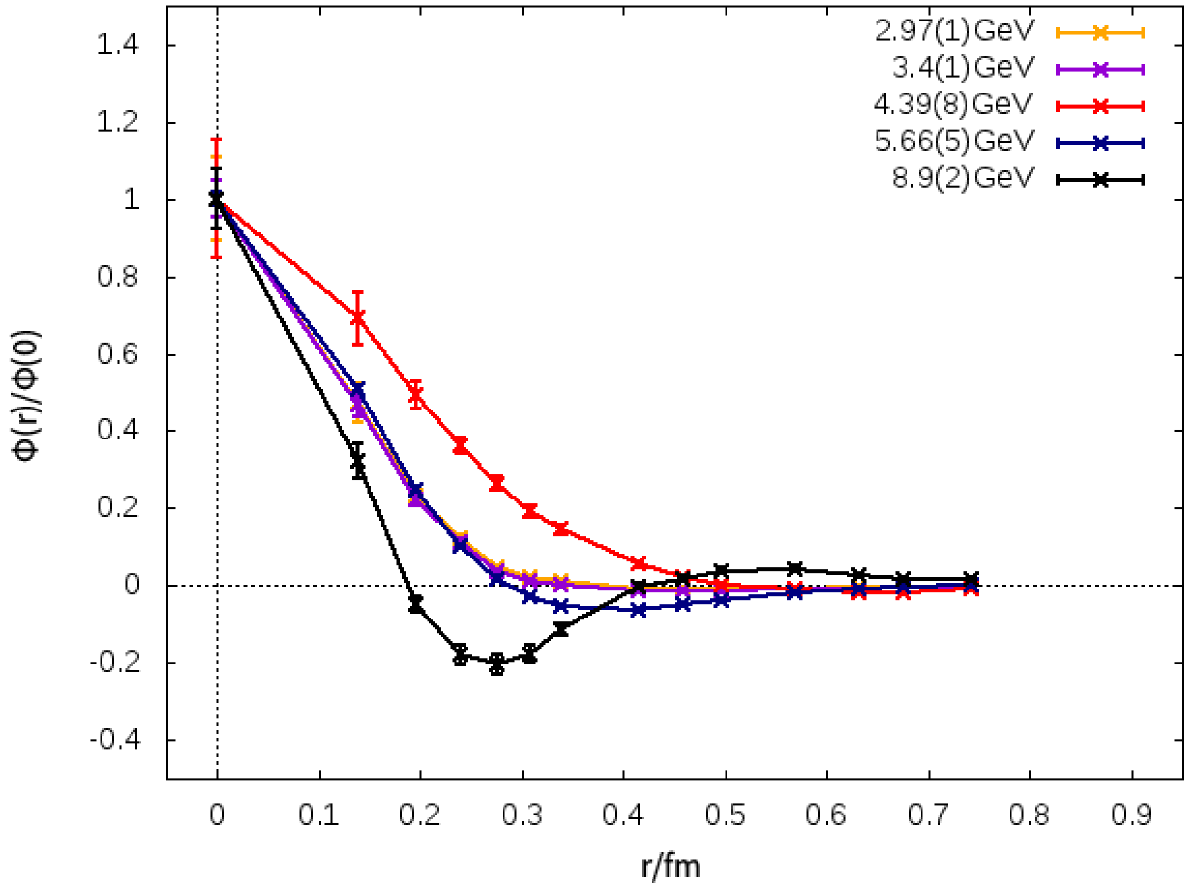
$|\epsilon_{ijk}|\bar{q}^a\gamma_i q^b B_j^{ab}$

0^{-+}

$\beta = 2.4$

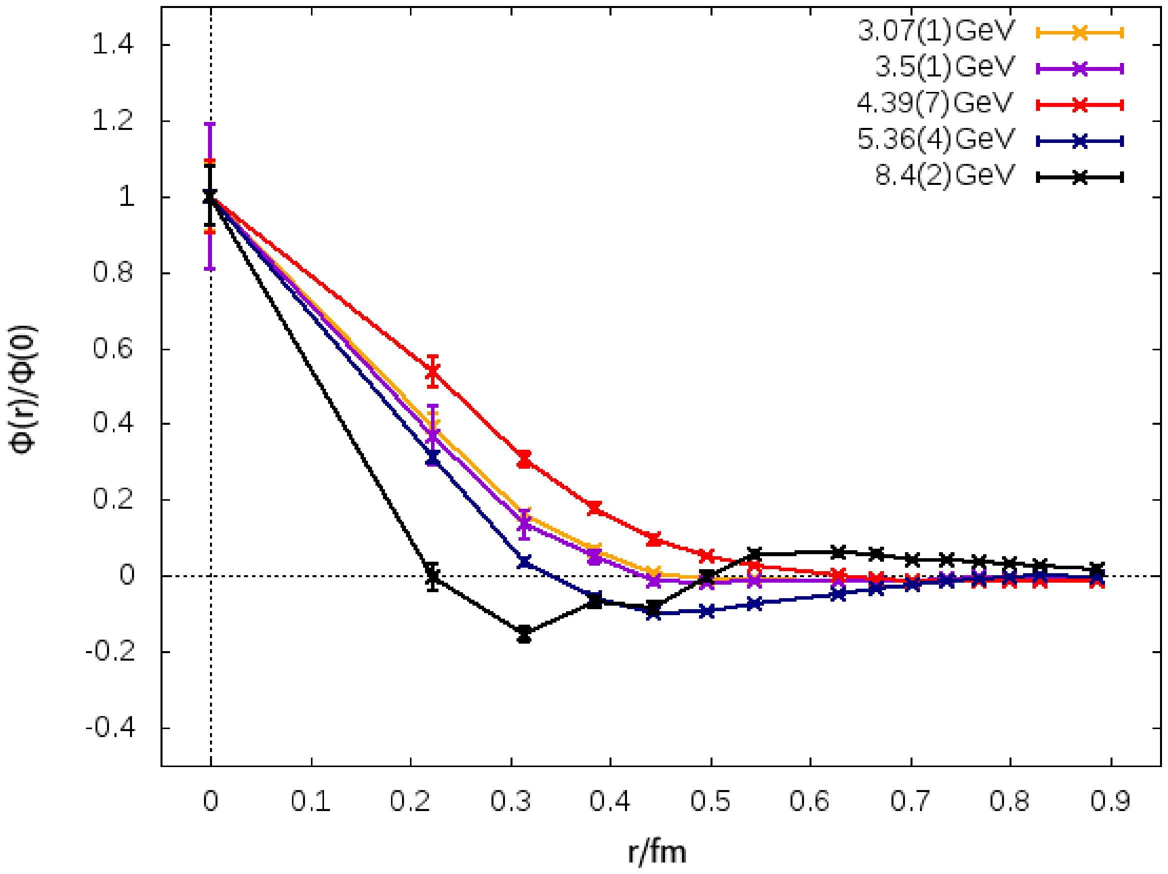


$\beta = 2.8$

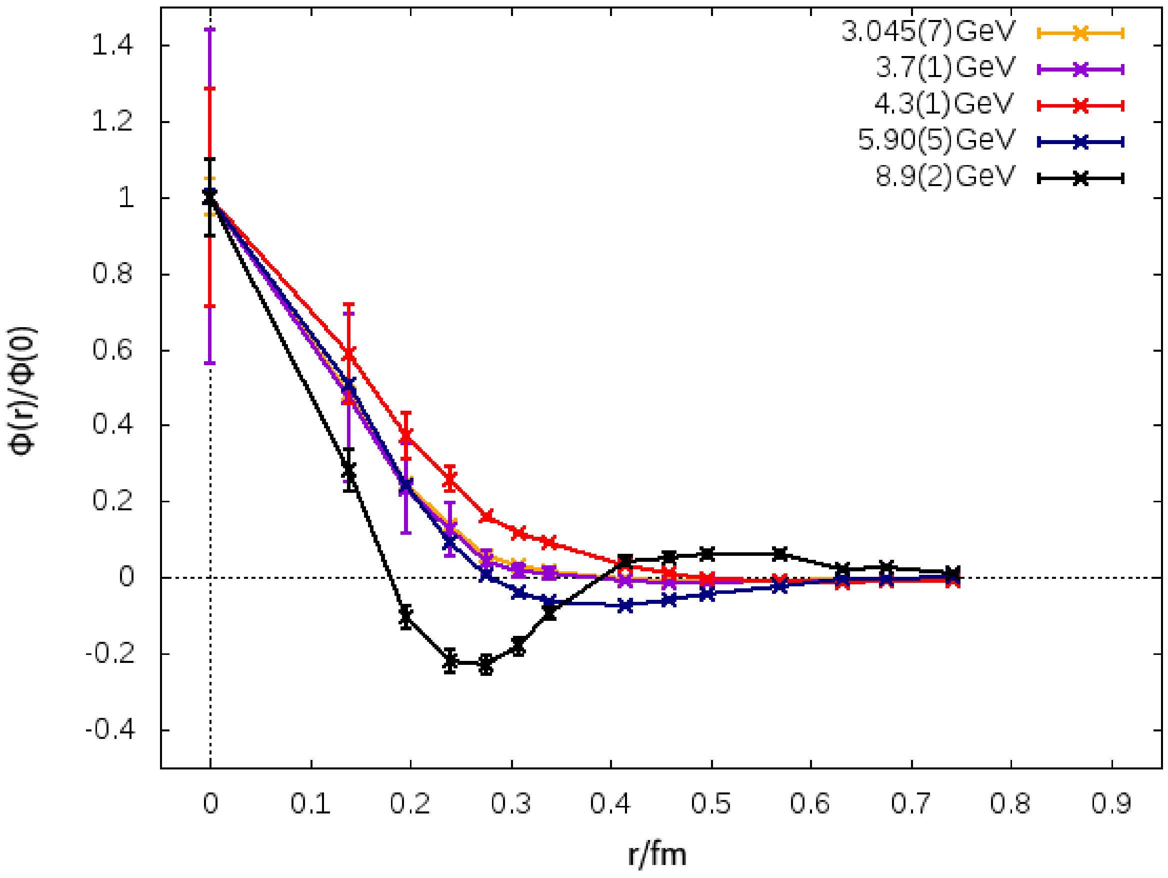


1^{--}

$\beta = 2.4$



$\beta = 2.8$

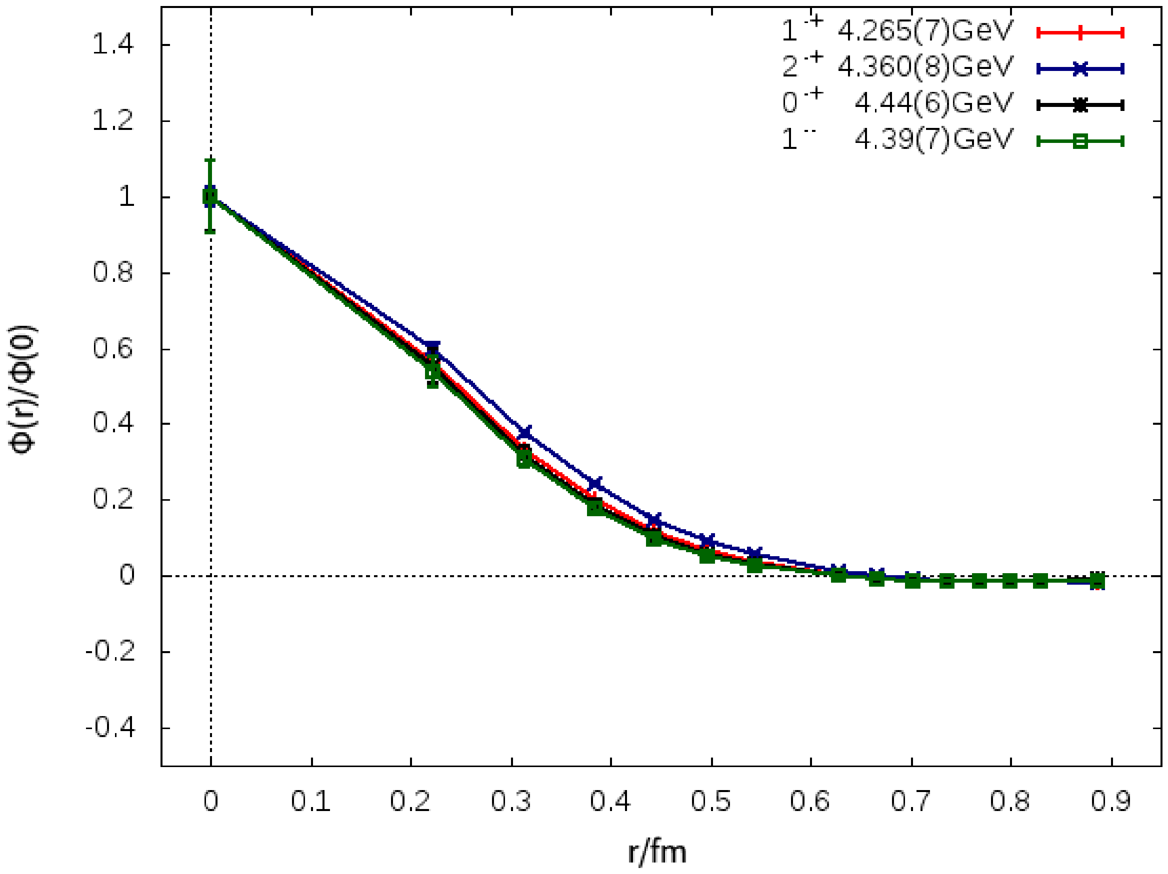


Masses From Fitting (Unit: GeV)

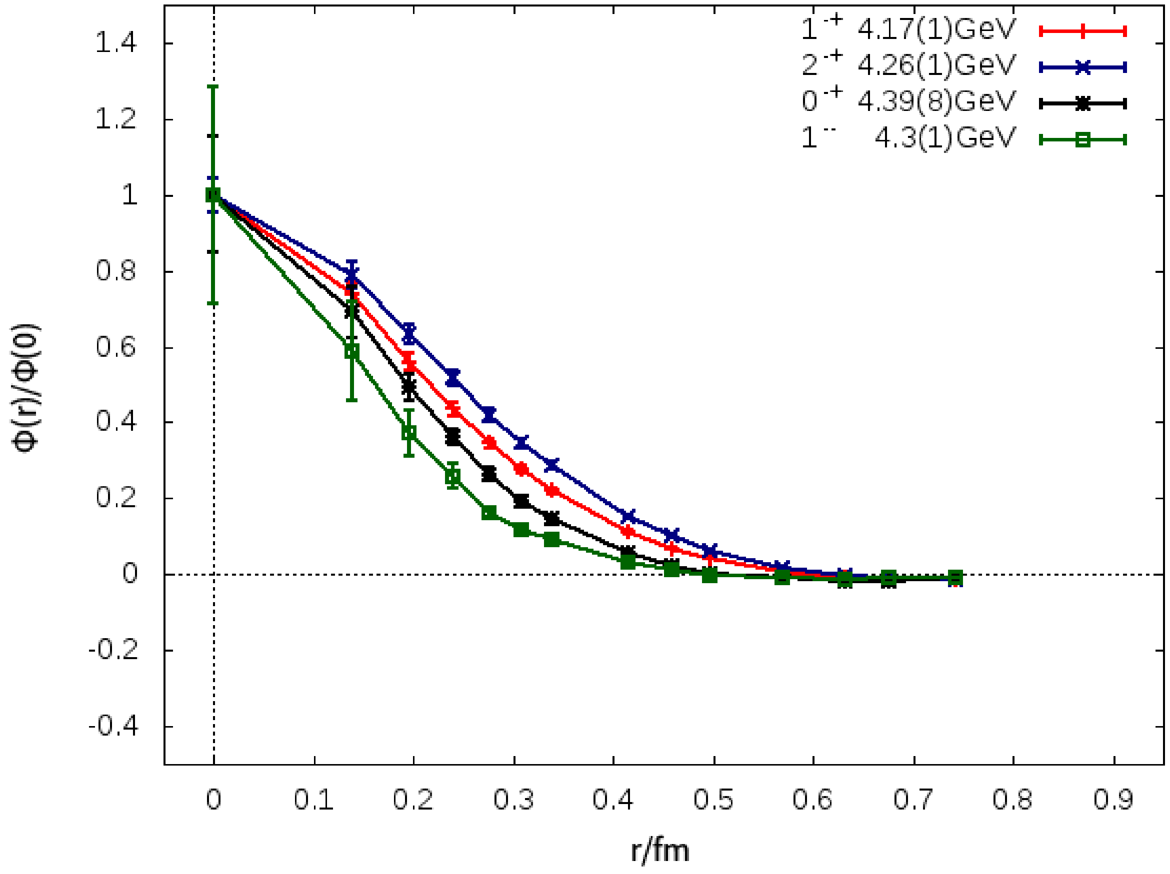
1^{--}		0^{-+}		1^{-+}		2^{-+}		node
$\beta = 2.4$	$\beta = 2.8$	$\beta = 2.4$	$\beta = 2.8$	$\beta = 2.4$	$\beta = 2.8$	$\beta = 2.4$	$\beta = 2.8$	
3.07(1)	3.045(7)	2.961(7)	2.97(1)	W	W	W	W	0
3.5(1)	3.7(1)	3.5(1)	3.4(1)	W	W	W	W	0
4.39(7)	4.3(1)	4.44(6)	4.39(8)	4.265(7)	4.17(1)	4.360(8)	4.26(1)	0
5.36(4)	5.90(5)	5.14(4)	5.66(5)	5.57(6)	5.39(5)	5.60(6)	5.59(5)	1
8.4(2)	8.9(2)	8.5(2)	8.9(2)	7.0(2)	7.45(7)	7.1(2)	7.69(8)	2

Hybrid 1S (states around 4.3GeV)

$\beta = 2.4$

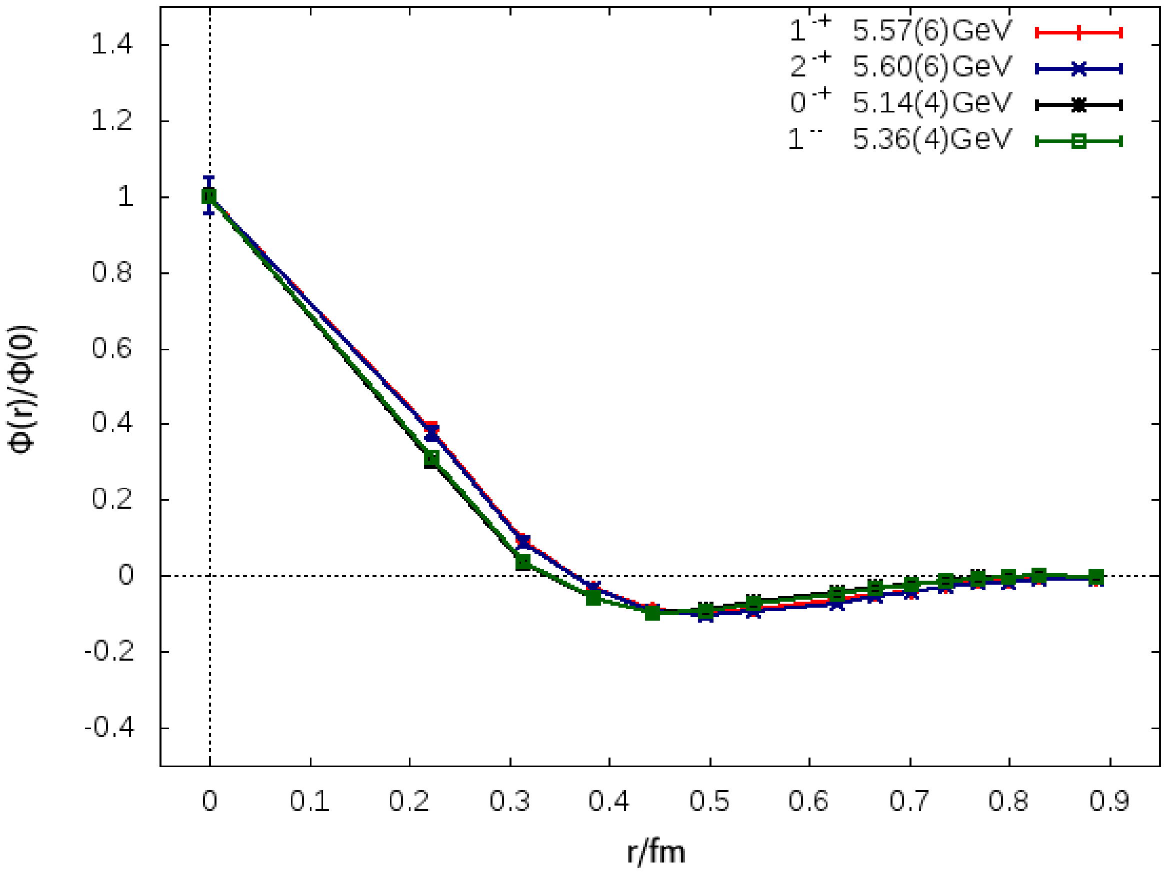


$\beta = 2.8$

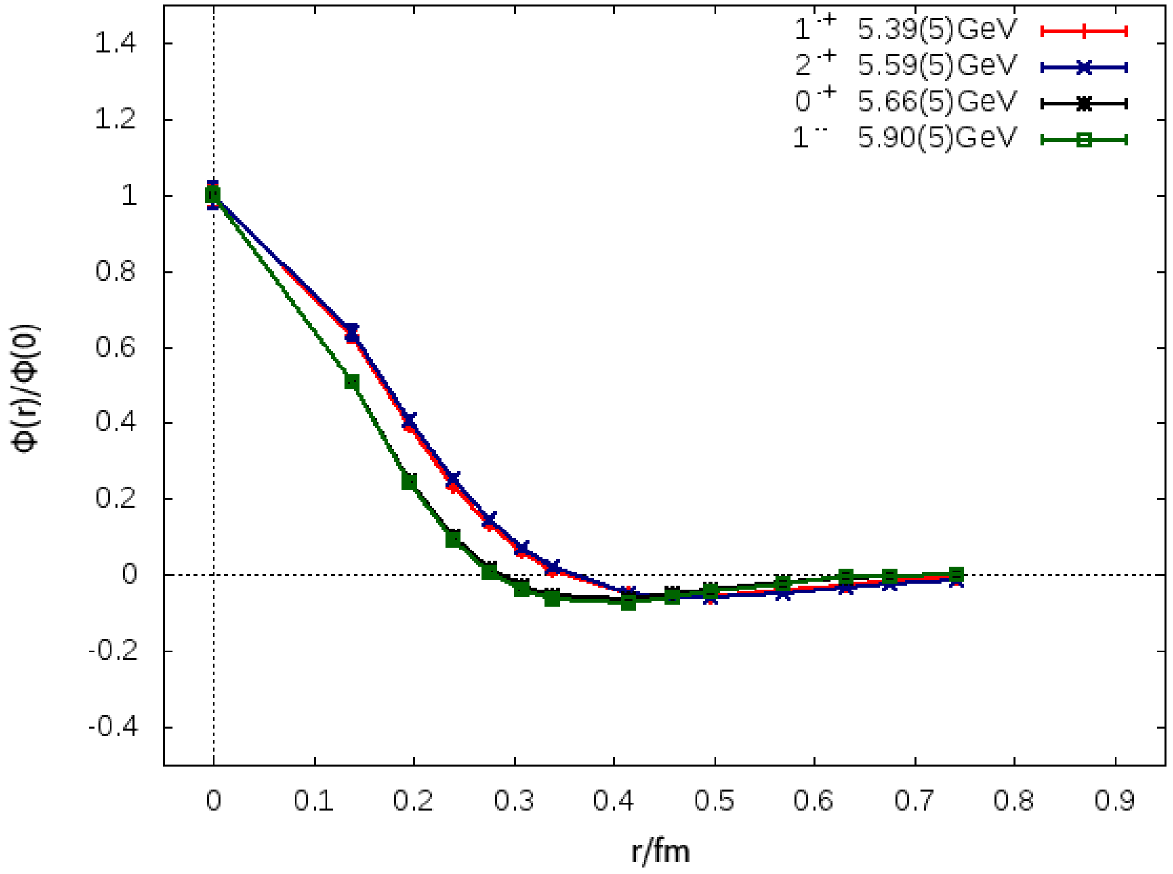


Hybrid 2S (states around 5.5GeV)

$\beta = 2.4$

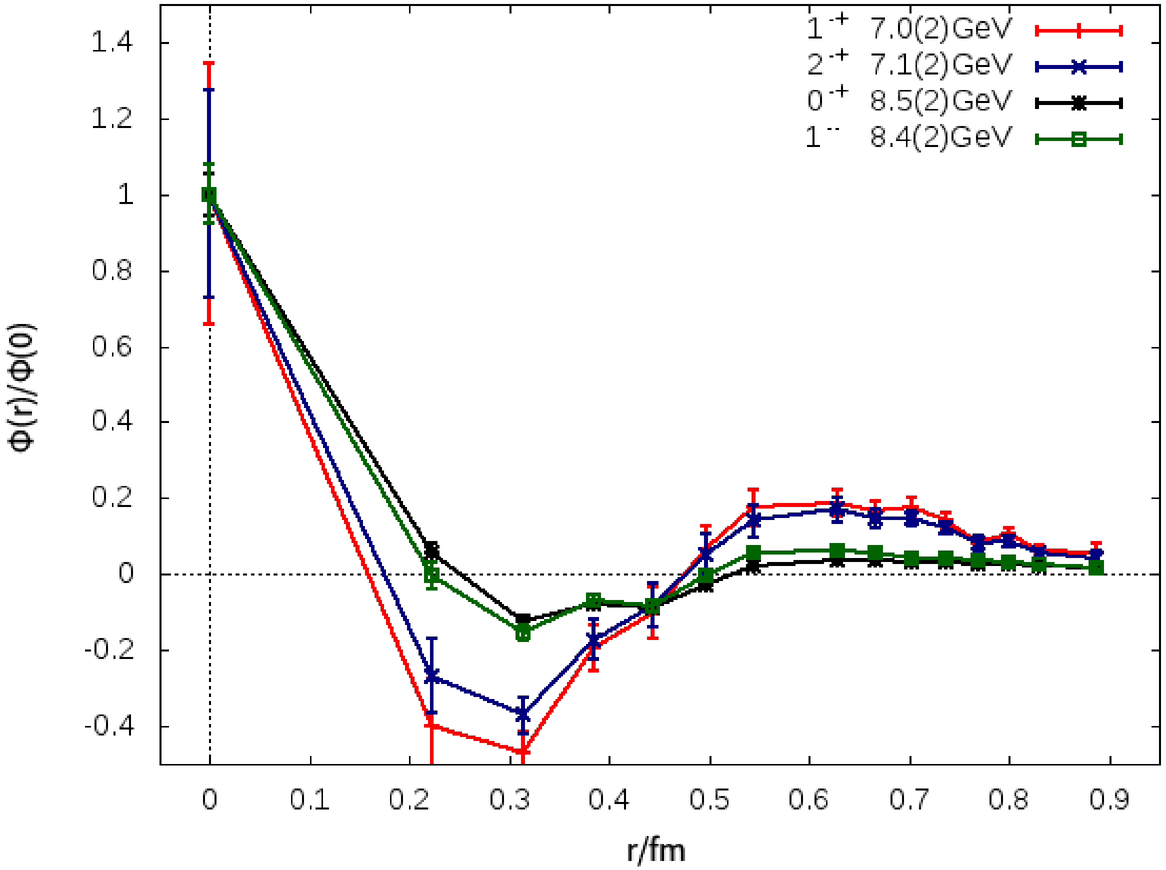


$\beta = 2.8$

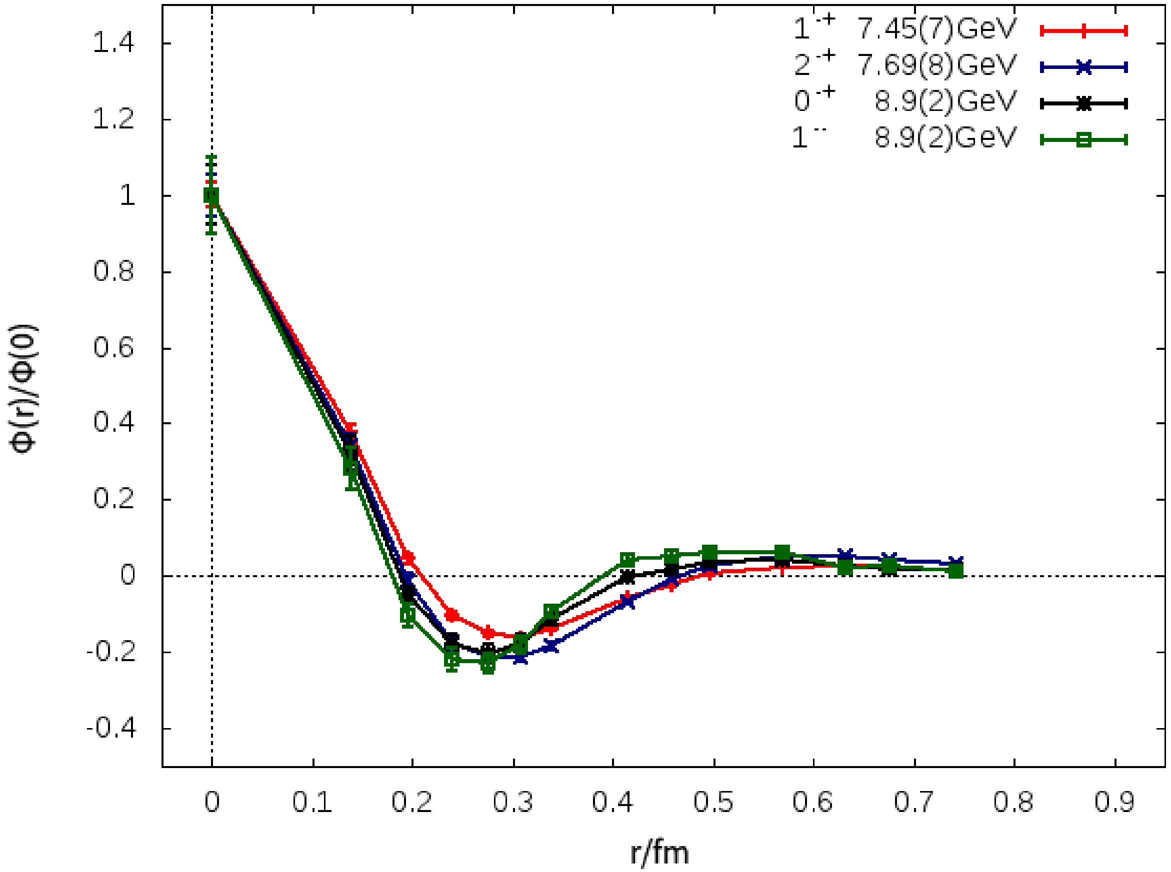


Hybrid 3S(?) (states above 7GeV)

$\beta = 2.4$

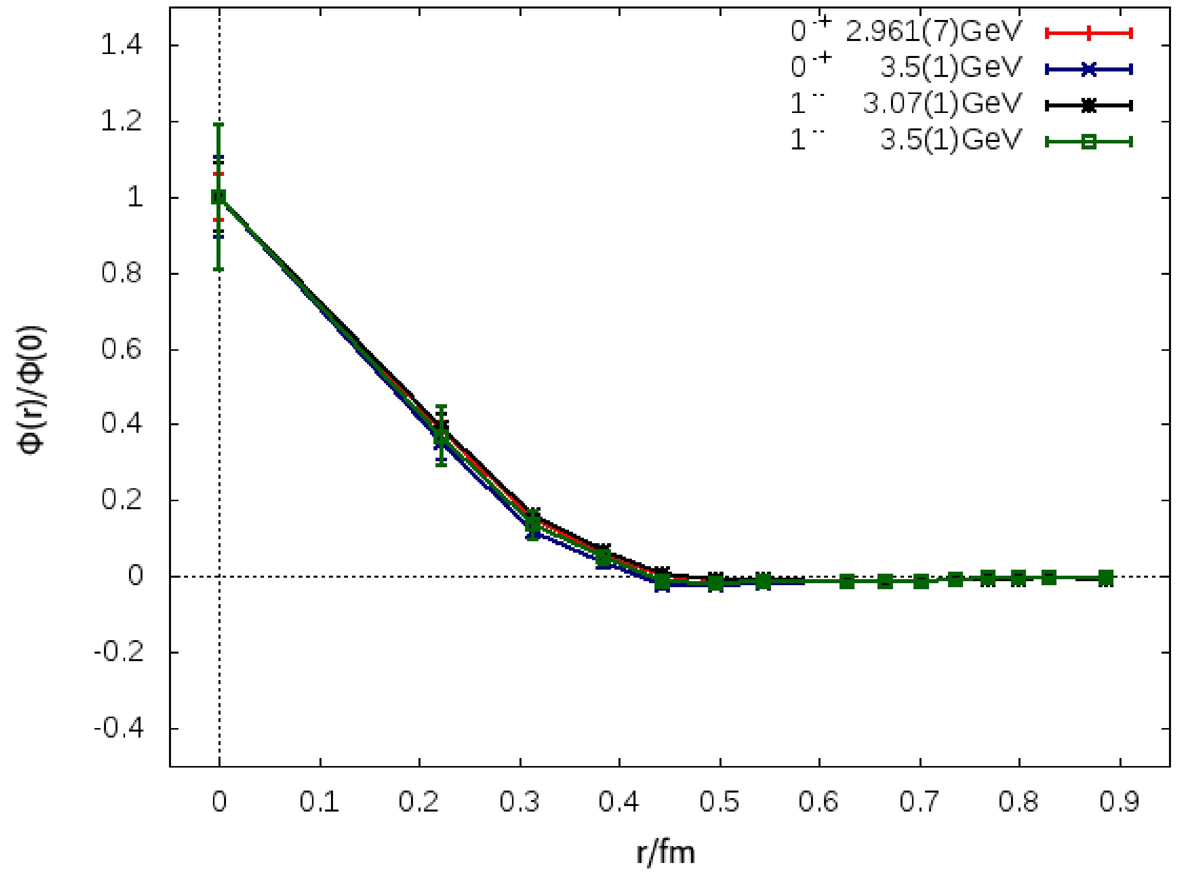


$\beta = 2.8$

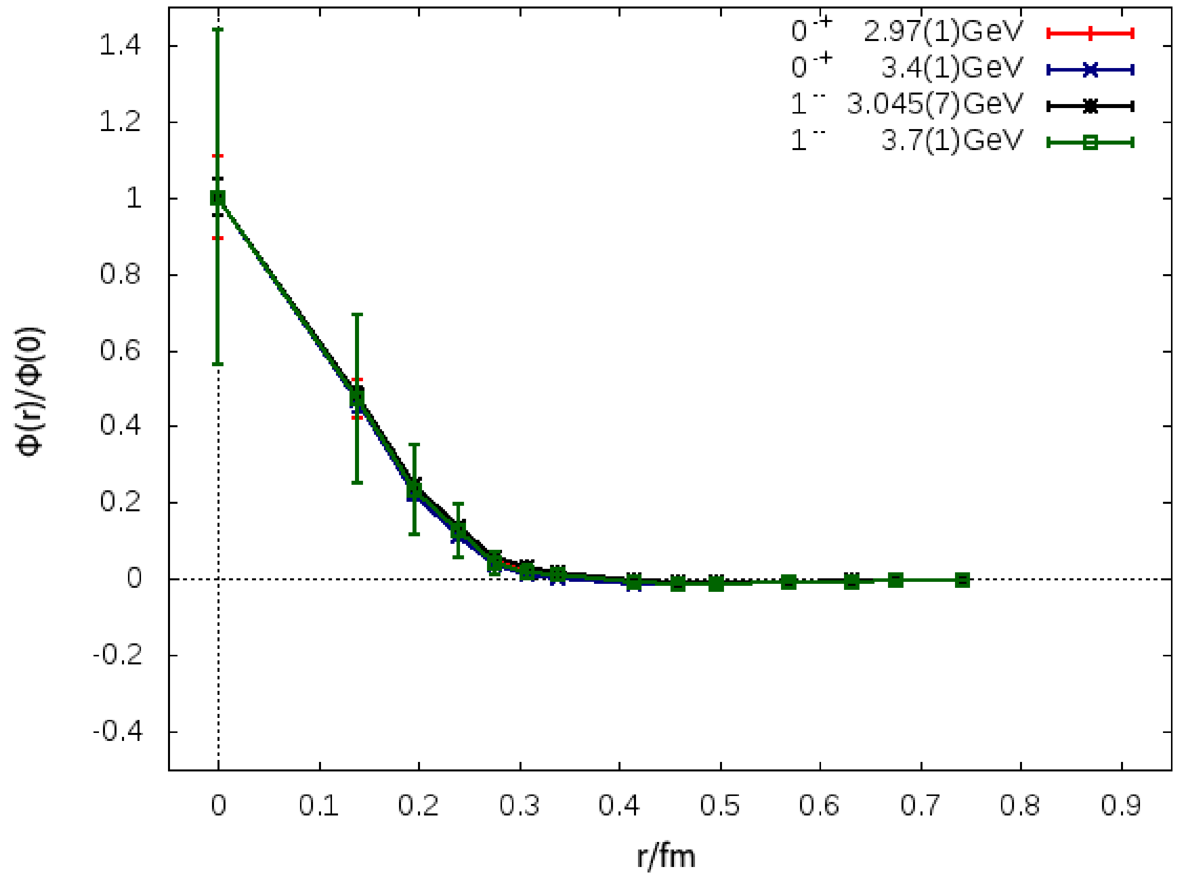


Conventional States($J/\psi, \psi', \eta_c, \eta_c'$, maybe)

$\beta = 2.4$



$\beta = 2.8$



Conclusion

- Clear nodal behavior of BS functions with respect to the spatial displacement reflects r in the operators is a meaningful dynamical variable.

- It implies that the inner structure of hybrid charmonia is a localized $\bar{c}c$ kernel surrounded by a gluonic component, just like a halo.

- The hybrid states distribute across 1^{--} and $(0,1,2)^{-+}$ have similar structure, and their masses are almost in degenerate around 4.3GeV(hybrid 1S) and 5.5GeV(hybrid 2S), respectively.

End of Story