Exotic Hadrons: models applied to LHCb pentaquarks

Tim Burns

Swansea University

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[T.B., Eur.Phys.J. A51, 152 (2015), 1509.02460]
[T.B. & E.Swanson (ongoing)]

Conventional and exotic hadrons

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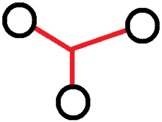
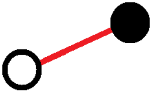
Baryons



Mesons



Conventional and exotic hadrons

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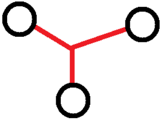

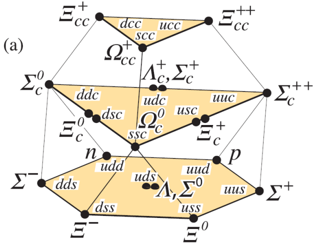

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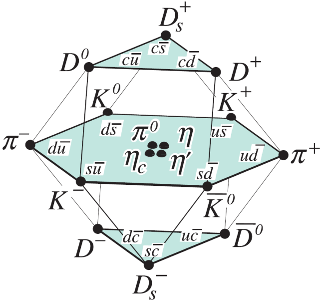
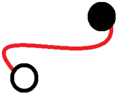


Conventional and exotic hadrons

Hybrids



Conventional and exotic hadrons

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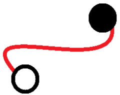
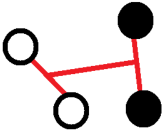
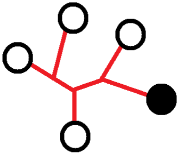


Compact multiquarks





Conventional and exotic hadrons

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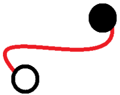

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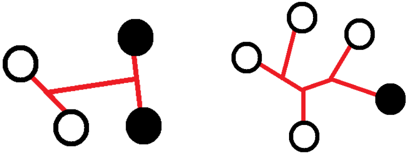
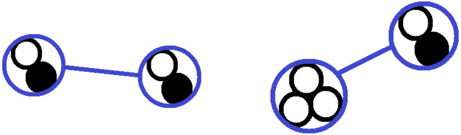


Hadronic molecules



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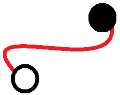

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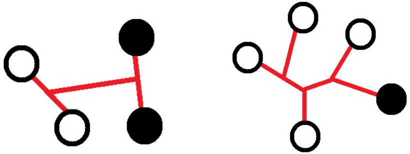
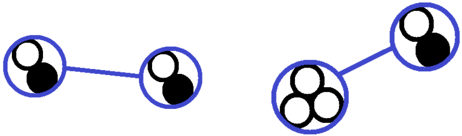
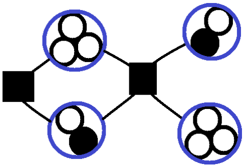


Hadronic molecules



Threshold effect

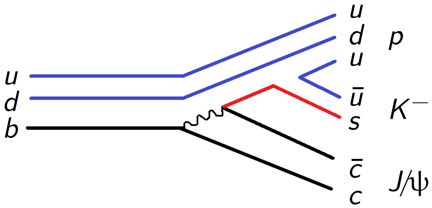


$P_c(4380)$ and $P_c(4450)$

$P_c(4380)$ and $P_c(4450)$

LHCb amplitude analysis of the three-body decay $\Lambda_b \to J/\psi p K^-$.

[LHCb,PRL115,072001,2015]



Two $J/\psi p$ states, the flavour of the proton with hidden charm ($uudc\bar{c}$).

$P_c(4380)$ and $P_c(4450)$

	$P_c(4380)^+$	$P_c(4450)^+$
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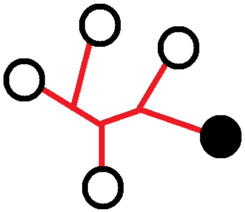
Compact pentaquark

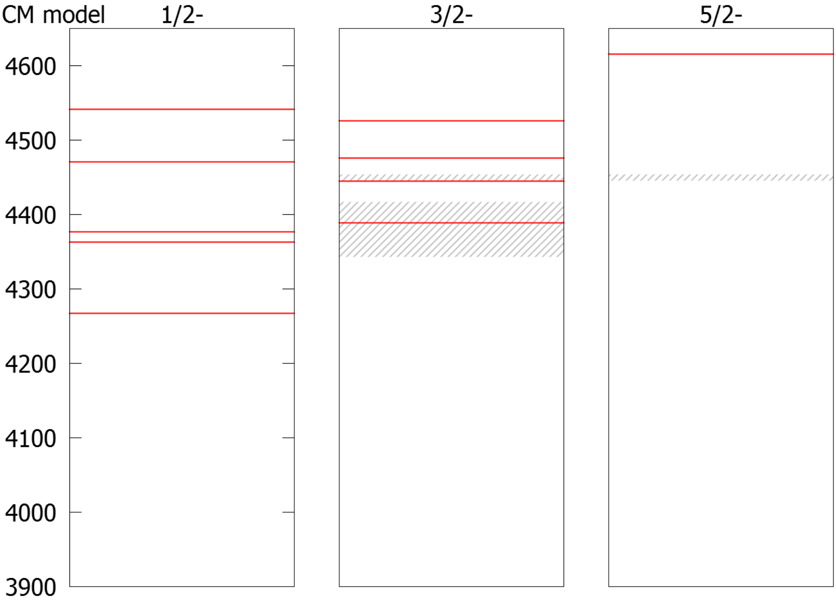


Compact pentaquark

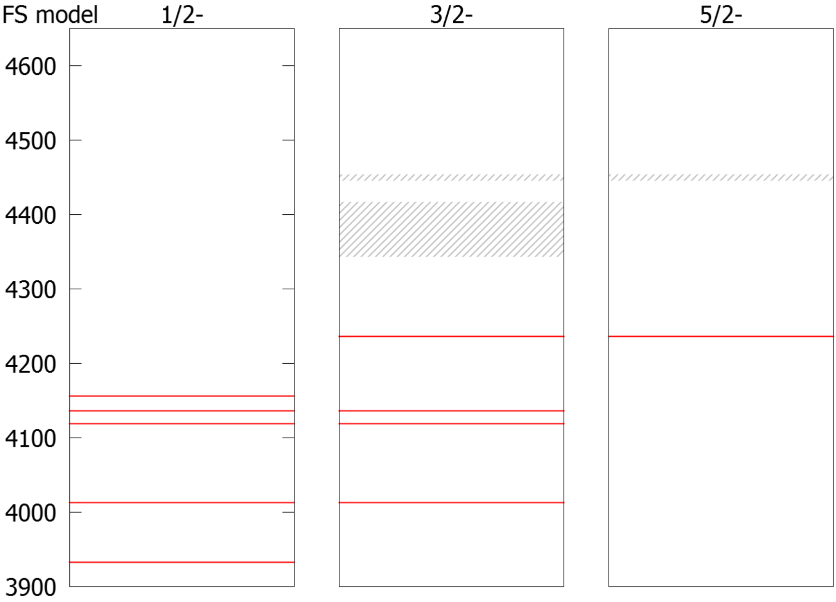
The $uudc\bar{c}$ combination in S-wave gives:

$I(J^P)$	$\|1\rangle$	$\|2\rangle$	$\|3\rangle$	$\|4\rangle$	$\|5\rangle$	$\|6\rangle$	$\|7\rangle$	$\|8\rangle$	$\|9\rangle$	$\|10\rangle$
$\frac{1}{2}\left(\frac{1}{2}^-\right)$	✓	✓			✓	✓		✓		
$\frac{1}{2}\left(\frac{3}{2}^-\right)$		✓				✓	✓	✓		
$\frac{1}{2}\left(\frac{5}{2}^-\right)$								✓		
$\frac{3}{2}\left(\frac{1}{2}^-\right)$				✓					✓	✓
$\frac{3}{2}\left(\frac{3}{2}^-\right)$			✓	✓						✓
$\frac{3}{2}\left(\frac{5}{2}^-\right)$				✓						

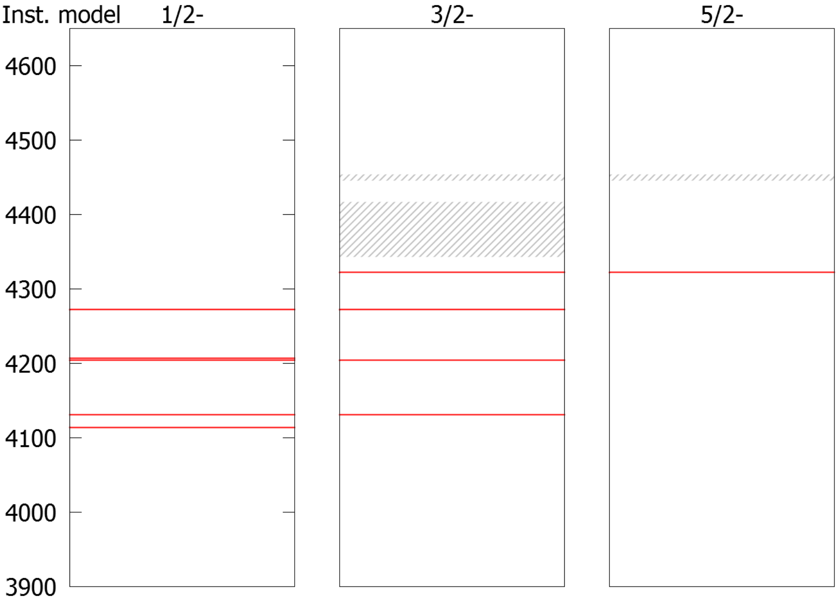
Compact pentaquark



Compact pentaquark



Compact pentaquark



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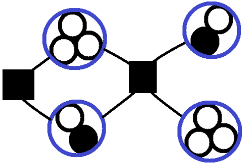

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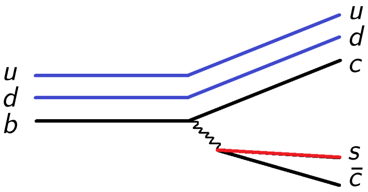
$\Sigma_c^+\bar{D}^{*0}$	$(udc)(u\bar{c})$		4459.9 ± 0.5
$\Lambda_c^+(1P)\bar{D}^0$	$(udc)(u\bar{c})$		4457.09 ± 0.35
$\chi_{c1}p$	$(udu)(c\bar{c})$		4448.93 ± 0.07

Threshold effect



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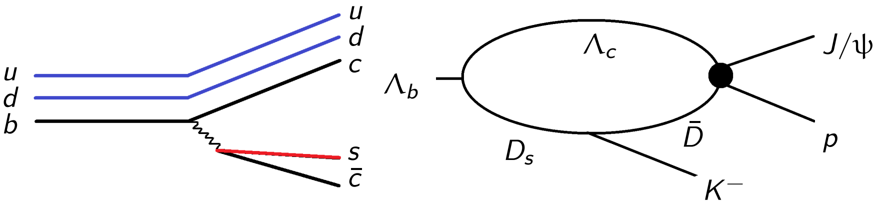
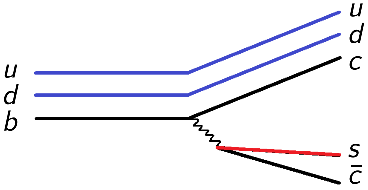
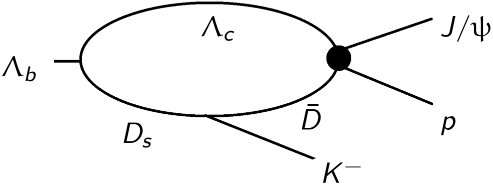
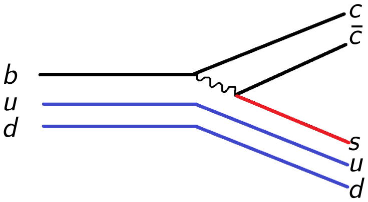


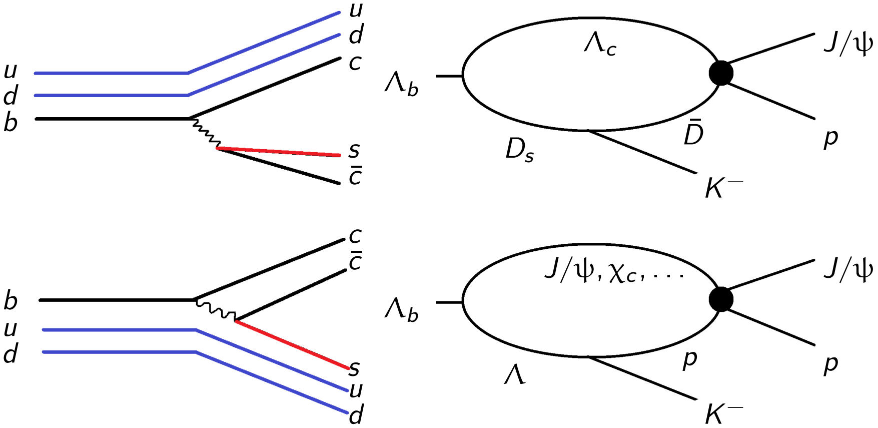
Threshold effect







Threshold effect



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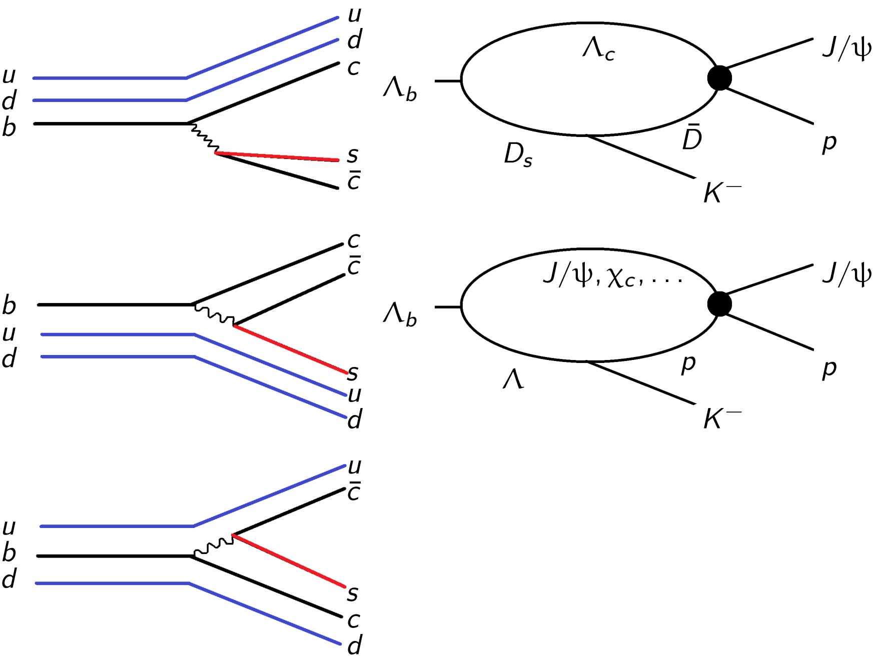

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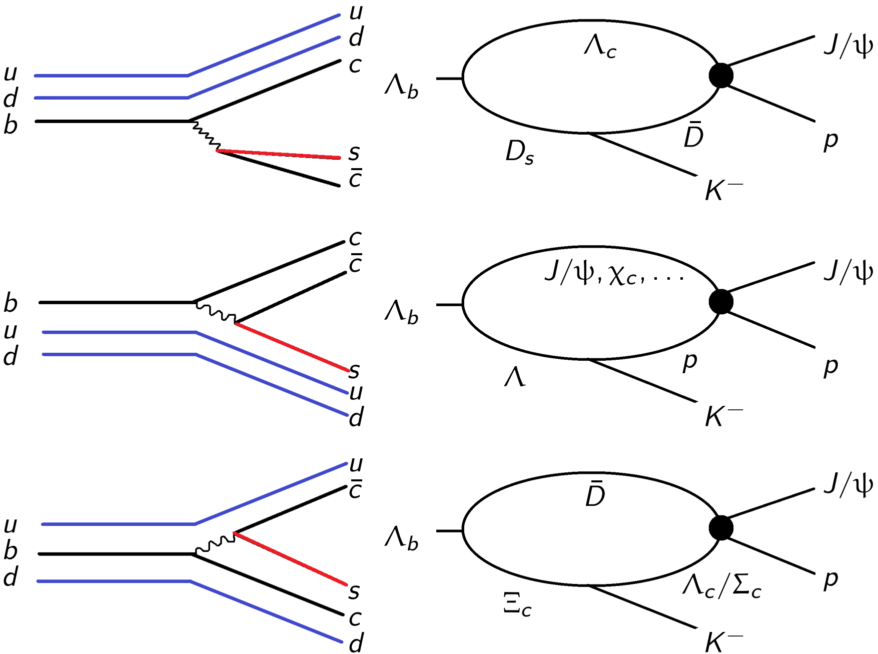
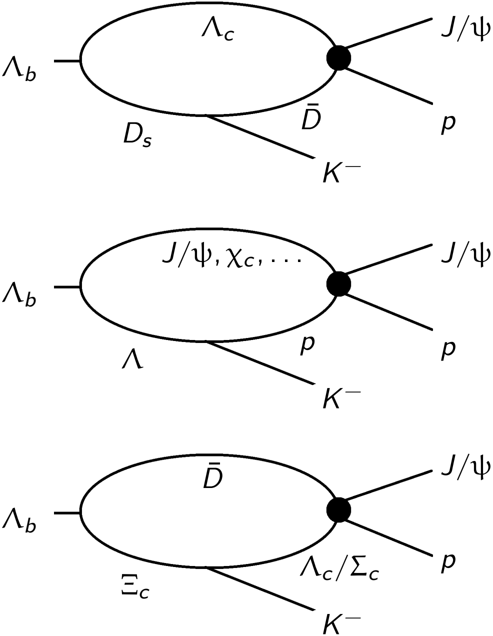


Threshold effect

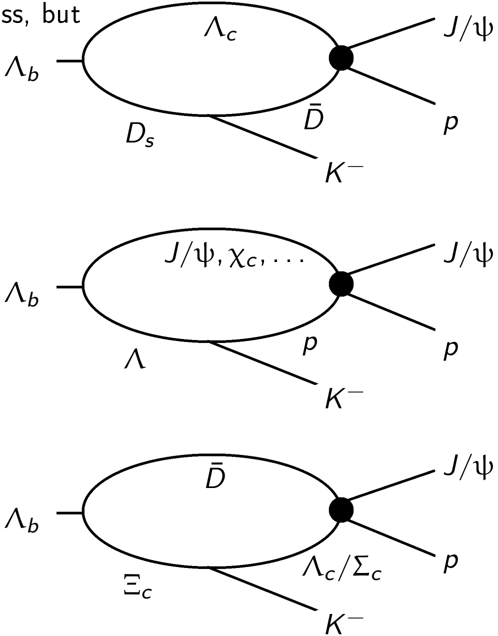
Enhancements expected at
$\Lambda_c \bar{D} = 1/2^-$
$\Lambda_c \bar{D}^* = 1/2^-, 3/2^-$
not seen at LHCb



Threshold effect

$\Lambda_c(1P)\bar{D} \approx P_c(4450)$ mass, but

- S-wave $= 1/2^+$
- P-wave $= 1/2^-, 3/2^-$
- why no $\Lambda_c(1P)\bar{D}^*$ states?



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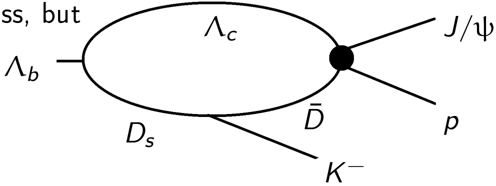
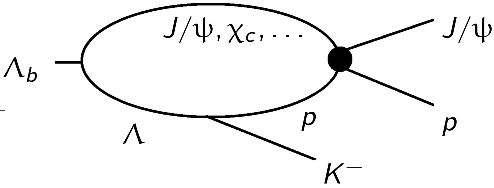
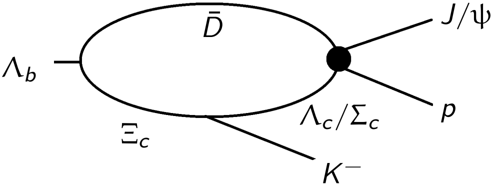


$\chi_{c1}p = P_c(4450)$ mass, but
- doubly suppressed
- S-wave $= 1/2^+, 3/2^+$
- P-wave $= 1/2^-, 3/2^-, 5/2^-$





Threshold effect

$\Lambda_c(1P)\bar{D} \approx P_c(4450)$ mass, but

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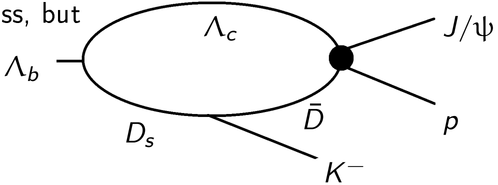

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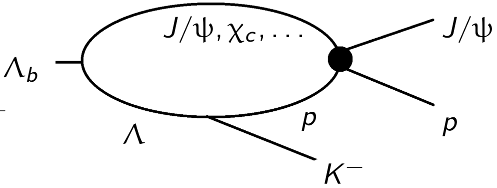
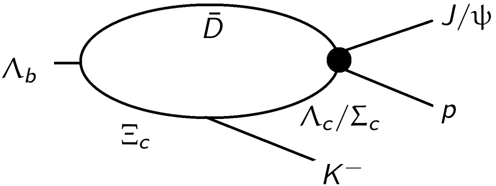
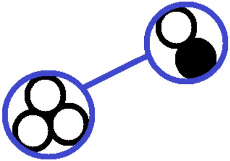


$\Sigma_c^*\bar{D} \approx P_c(4380)$ mass, and
$\Sigma_c\bar{D}^* \approx P_c(4450)$ mass, but

- doubly suppressed
- what restricts J^P?
- why not $\Sigma_c\bar{D}, \Sigma_c^*\bar{D}^*$?

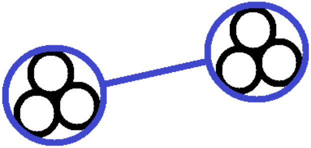


Hadronic molecule

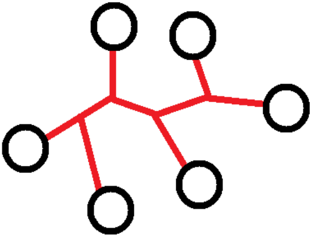


Hadronic molecule

Consider the deuteron, a $0(1^-)$ state 2.2 MeV below *pn* threshold.



vs.



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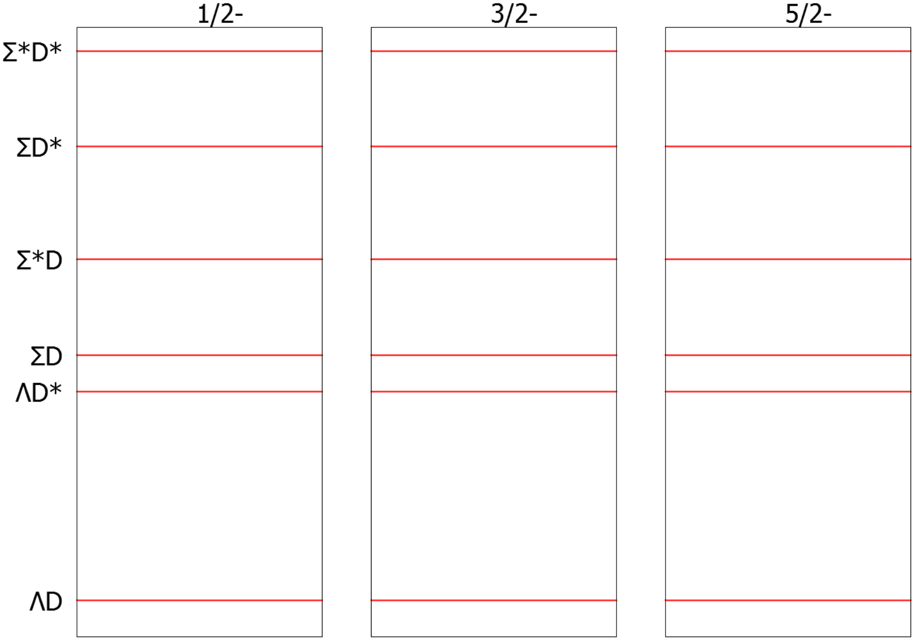
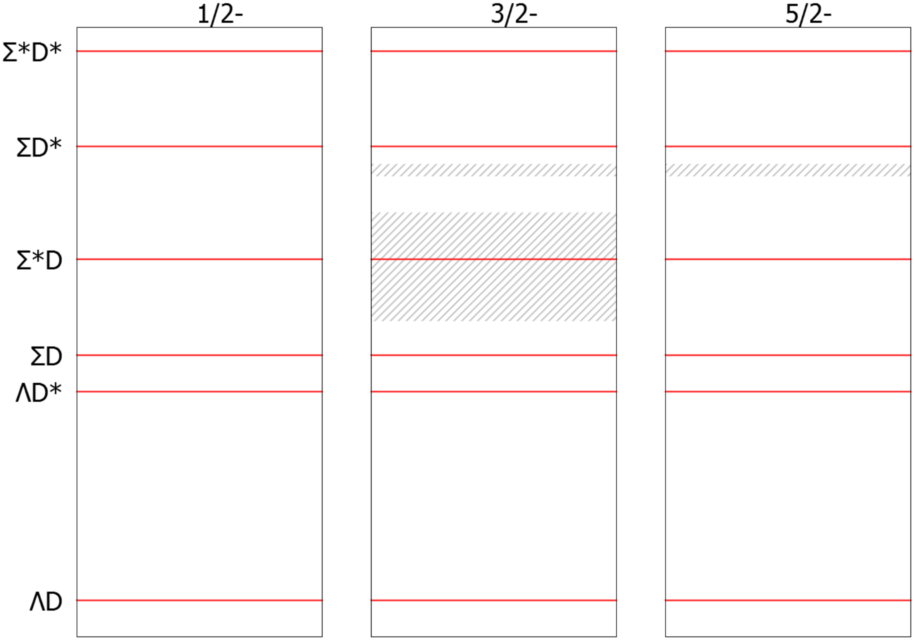
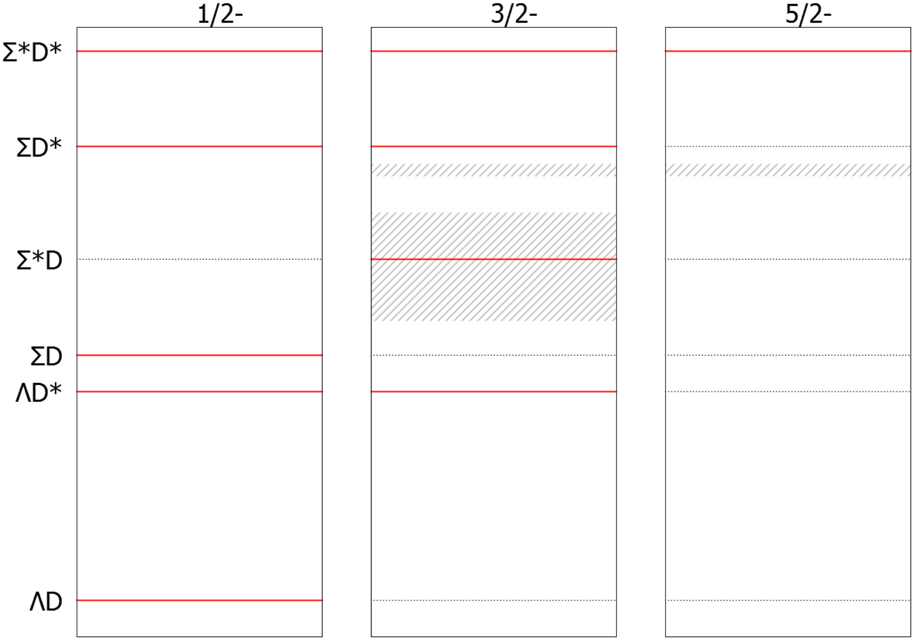
Hadronic molecule

The $(udc)(u\bar{c})$ combinations in S-wave are:

$I(J^P)$	$\Lambda_c\bar{D}$	$\Lambda_c\bar{D}^*$	$\Sigma_c\bar{D}$	$\Sigma_c^*\bar{D}$	$\Sigma_c\bar{D}^*$	$\Sigma_c^*\bar{D}^*$
$\frac{1}{2}\left(\frac{1}{2}^-\right)$	✓	✓	✓		✓	✓
$\frac{1}{2}\left(\frac{3}{2}^-\right)$		✓		✓	✓	✓
$\frac{1}{2}\left(\frac{5}{2}^-\right)$						✓
$\frac{3}{2}\left(\frac{1}{2}^-\right)$			✓		✓	✓
$\frac{3}{2}\left(\frac{3}{2}^-\right)$				✓	✓	✓
$\frac{3}{2}\left(\frac{5}{2}^-\right)$						✓


1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD

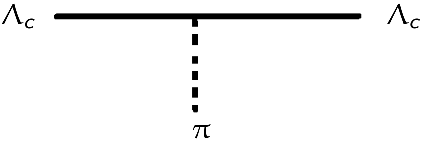

1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD



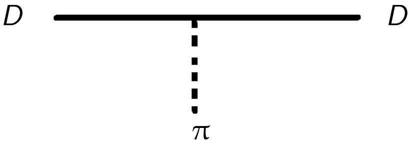
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD

Hadronic molecule

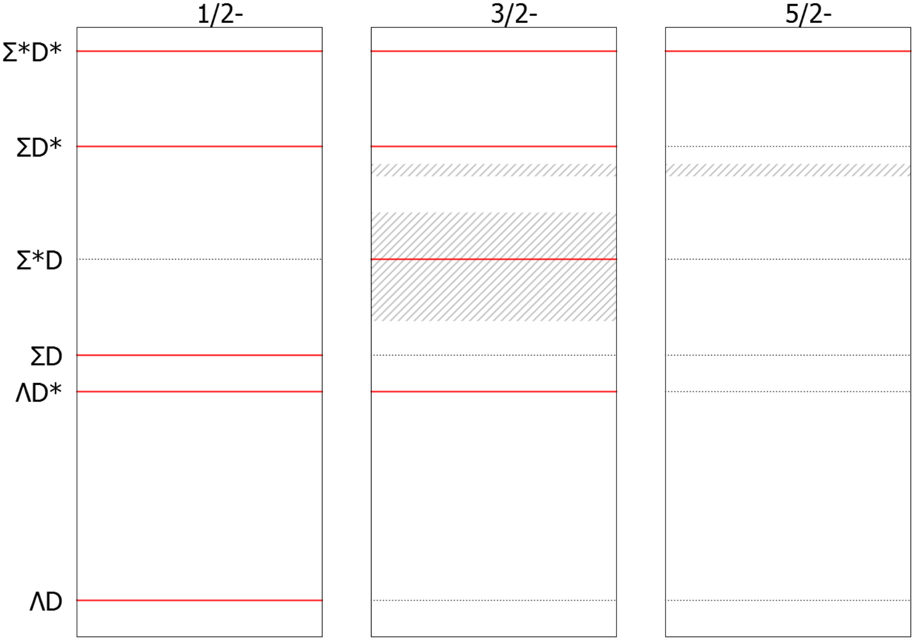
Forbidden vertices:

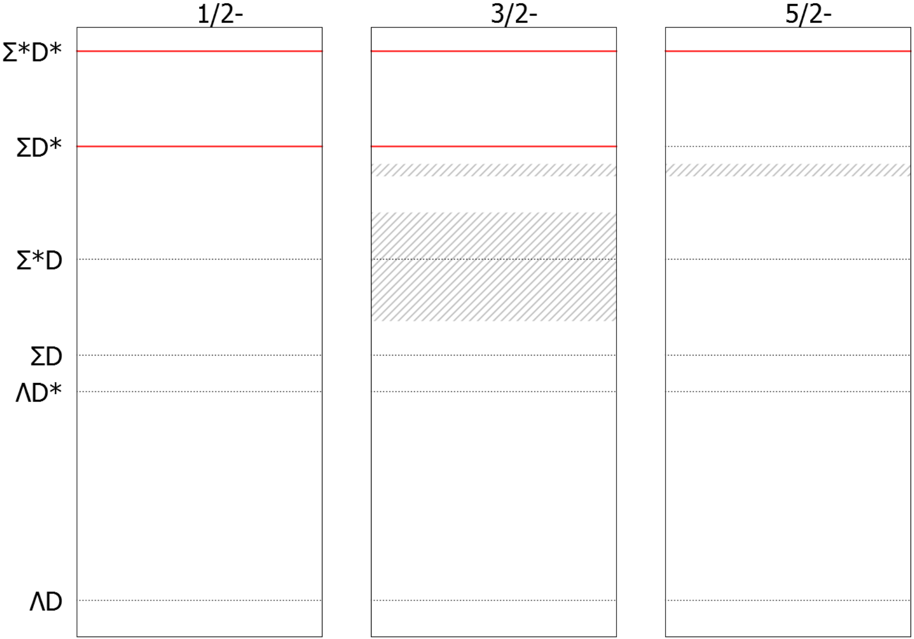


$0 \nrightarrow 0 + 1$ (isospin)



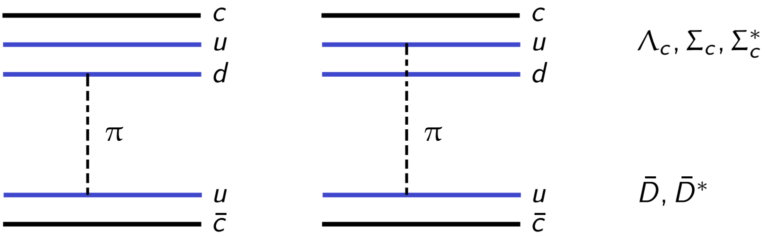
$0^- \nrightarrow 0^- + 0^-$ (spin-parity)


1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD



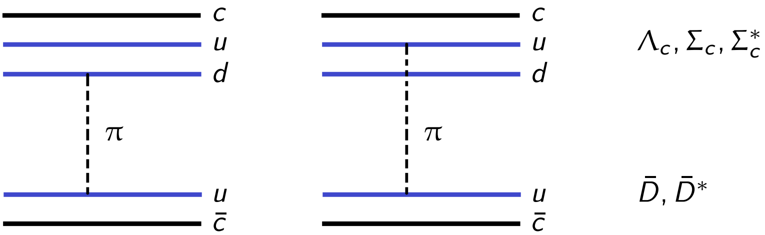
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD

Hadronic molecule



$$V(\vec{r}) = \sum_{ij} \left[C(r)\vec{\sigma}_i \cdot \vec{\sigma}_j + T(r) S_{ij}(\hat{r}) \right] \vec{\tau}_i \cdot \vec{\tau}_j$$

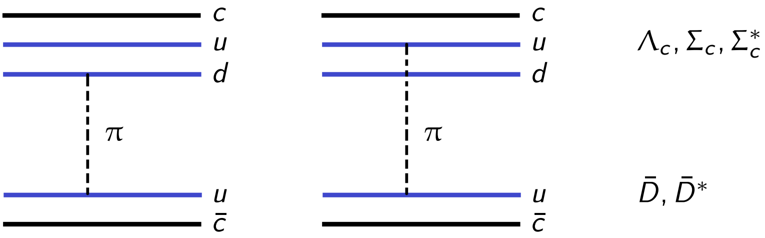
Hadronic molecule



$$V(\vec{r}) = \sum_{ij} \left[C(r)\vec{\sigma}_i \cdot \vec{\sigma}_j + T(r)S_{ij}(\hat{r}) \right] \vec{\tau}_i \cdot \vec{\tau}_j$$

All $I = 3/2$ potentials suppressed by $-1/2$.

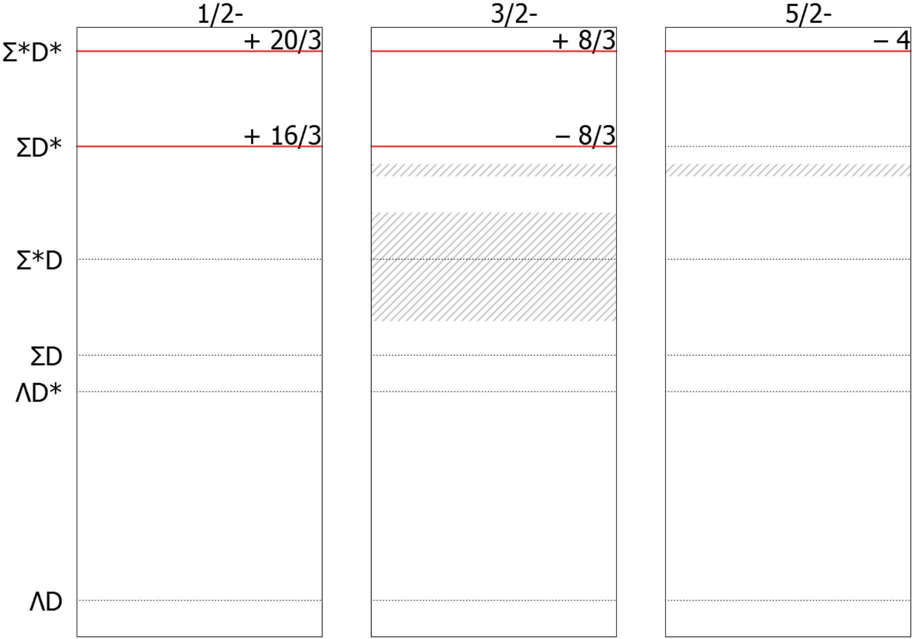
Hadronic molecule



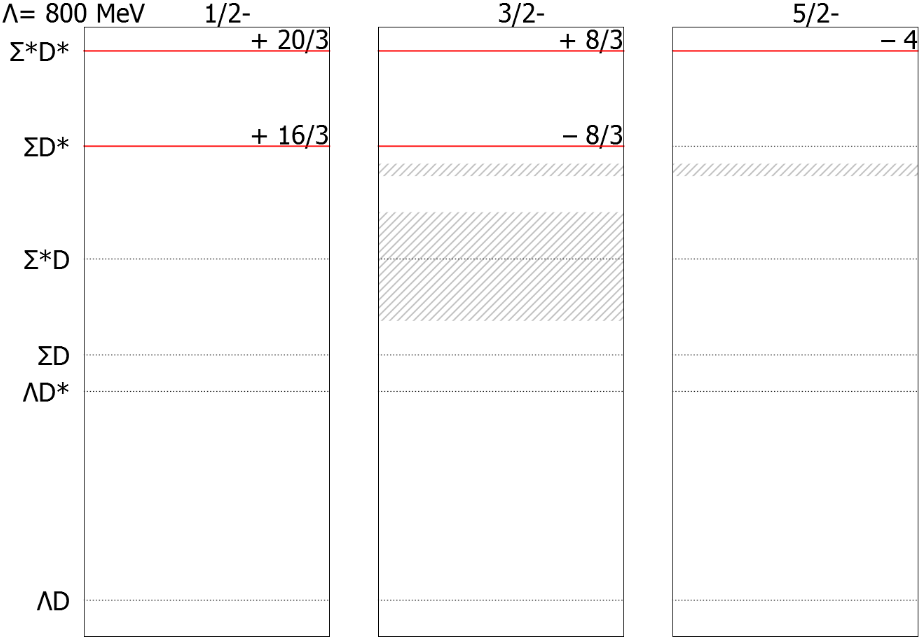
$$V(\vec{r}) = \sum_{ij} \left[C(r) \vec{\sigma}_i \cdot \vec{\sigma}_j + T(r) S_{ij}(\hat{r}) \right] \vec{\tau}_i \cdot \vec{\tau}_j$$

All $I = 3/2$ potentials suppressed by $-1/2$.

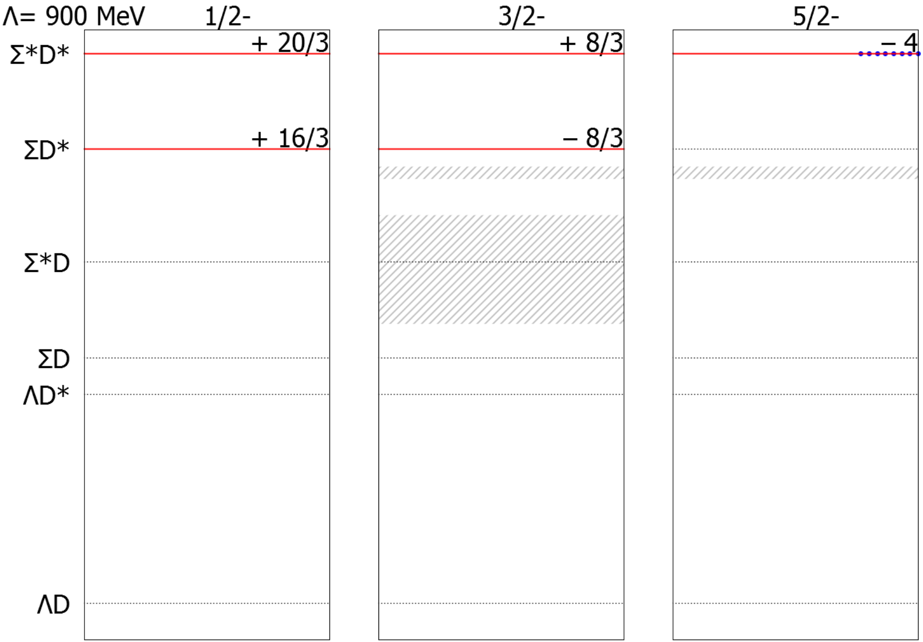
Coefficient of $C(r)$ is important.



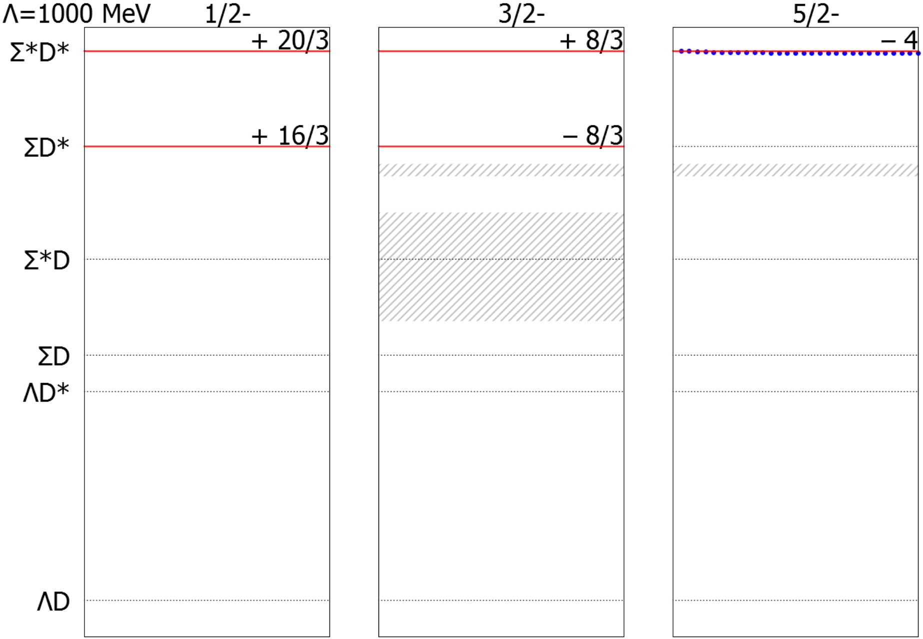
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



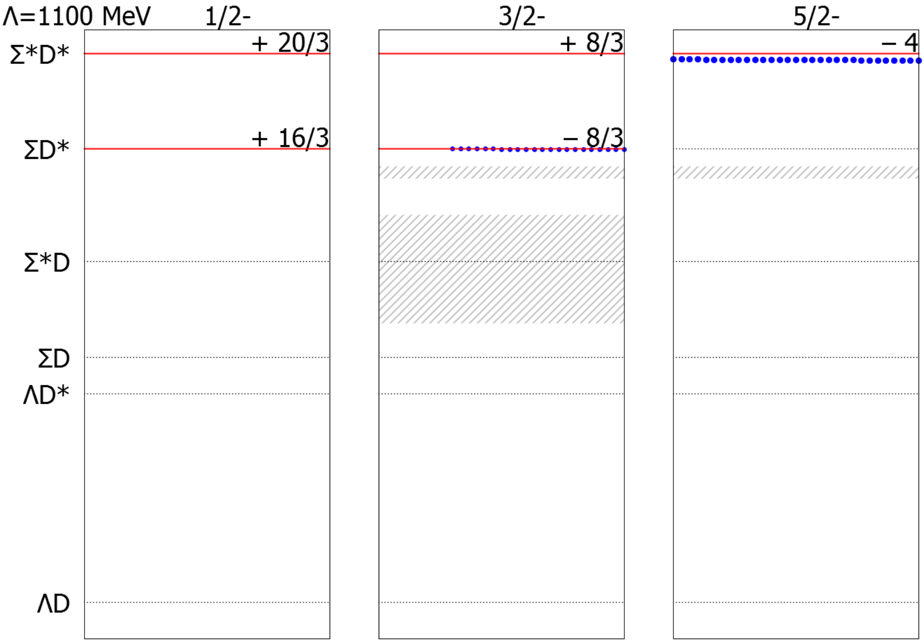
Λ= 800 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



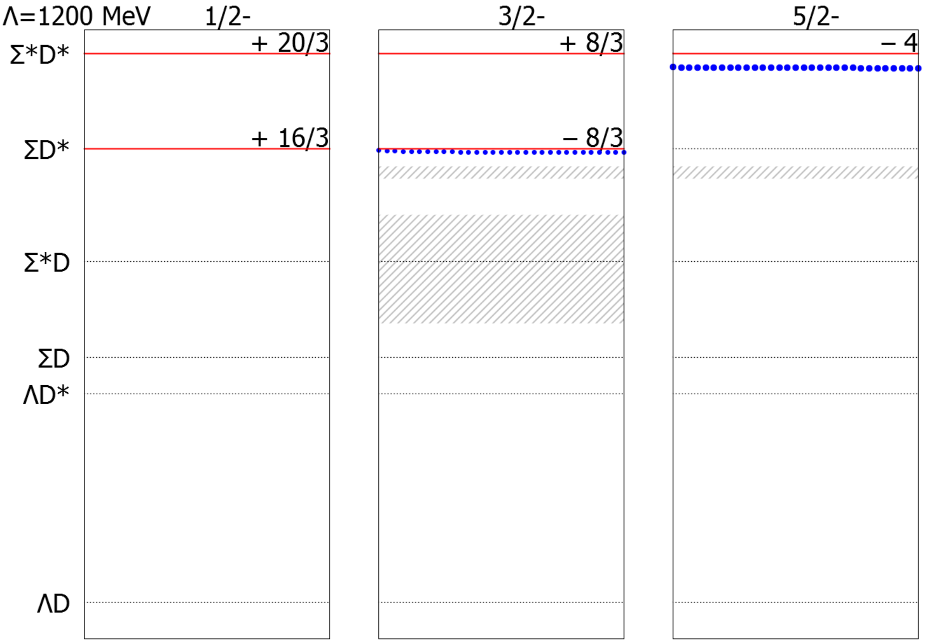
Λ= 900 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



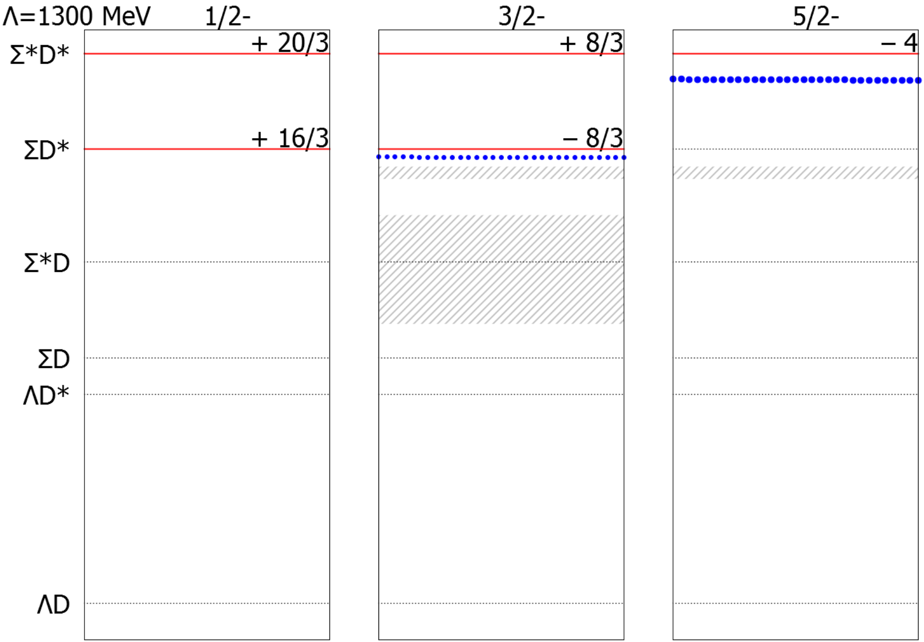
Λ=1000 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



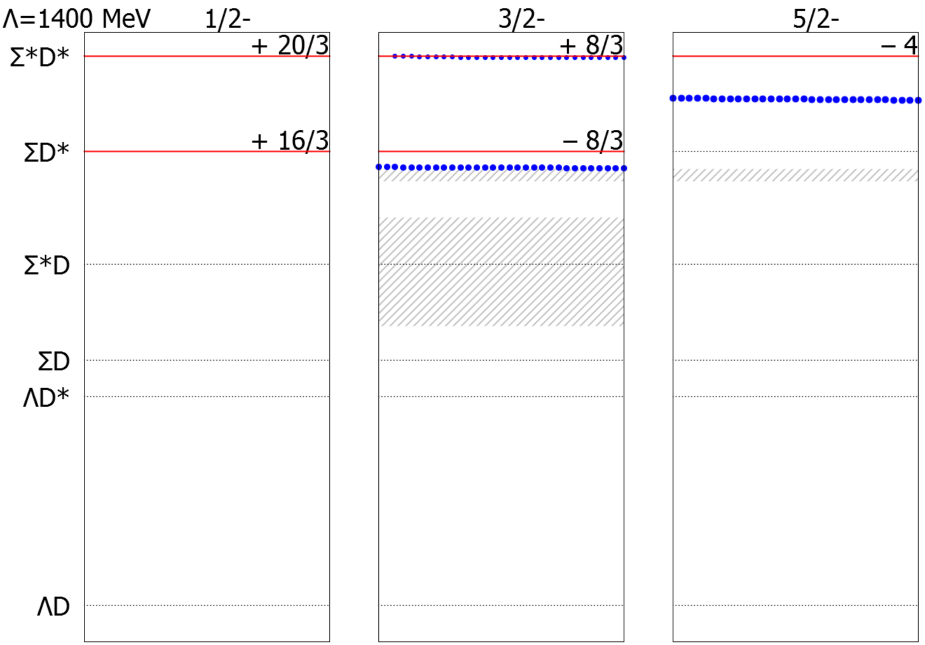
Λ=1100 MeV
1/2-
3/2-
5/2-
+ 20/3
+ 8/3
− 4
Σ*D*
+ 16/3
− 8/3
ΣD*
Σ*D
ΣD
ΛD*
ΛD



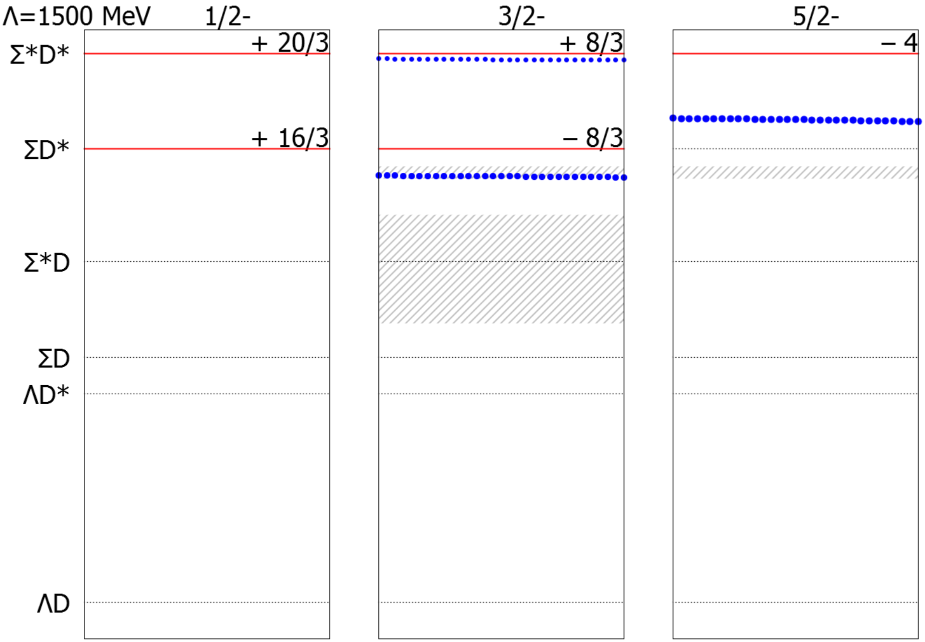
Λ=1200 MeV
1/2-
3/2-
5/2-
+ 20/3
+ 8/3
− 4
+ 16/3
− 8/3
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD



Λ=1300 MeV
1/2-
3/2-
5/2-
+ 20/3
+ 8/3
− 4
+ 16/3
− 8/3
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD



Λ=1400 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



Λ=1500 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4

Hadronic molecule

$I(J^P)$	$\Lambda_c \bar{D}$	$\Lambda_c \bar{D}^*$	$\Sigma_c \bar{D}$	$\Sigma_c^* \bar{D}$	$\Sigma_c \bar{D}^*$	$\Sigma_c^* \bar{D}^*$
$\frac{1}{2}\left(\frac{1}{2}^-\right)$	✓	✓	✓		✓	✓
$\frac{1}{2}\left(\frac{3}{2}^-\right)$		✓		✓	✓	✓
$\frac{1}{2}\left(\frac{5}{2}^-\right)$						✓
$\frac{3}{2}\left(\frac{1}{2}^-\right)$			✓		✓	✓
$\frac{3}{2}\left(\frac{3}{2}^-\right)$				✓	✓	✓
$\frac{3}{2}\left(\frac{5}{2}^-\right)$						✓

Hadronic molecule

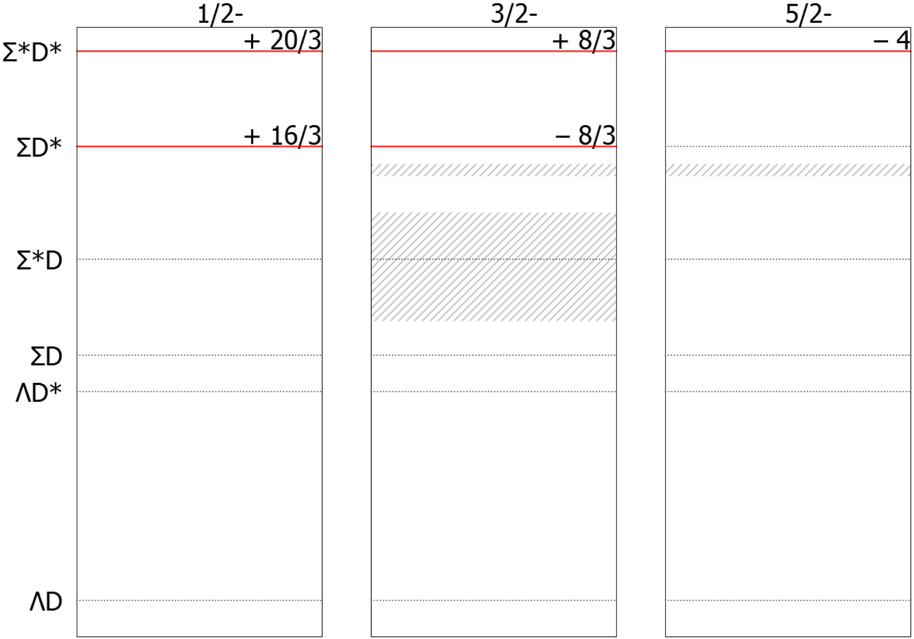
$I(J^P)$	$\Lambda_c \bar{D}$	$\Lambda_c \bar{D}^*$	$\Sigma_c \bar{D}$	$\Sigma_c^* \bar{D}$	$\Sigma_c \bar{D}^*$	$\Sigma_c^* \bar{D}^*$
$\frac{1}{2}\left(\frac{1}{2}^-\right)$	✓	✓	✓		✓	✓
$\frac{1}{2}\left(\frac{3}{2}^-\right)$		✓		✓	✓	✓
$\frac{1}{2}\left(\frac{5}{2}^-\right)$						✓
$\frac{3}{2}\left(\frac{1}{2}^-\right)$			✓		✓	✓
$\frac{3}{2}\left(\frac{3}{2}^-\right)$				✓	✓	✓
$\frac{3}{2}\left(\frac{5}{2}^-\right)$						✓

Hadronic molecule

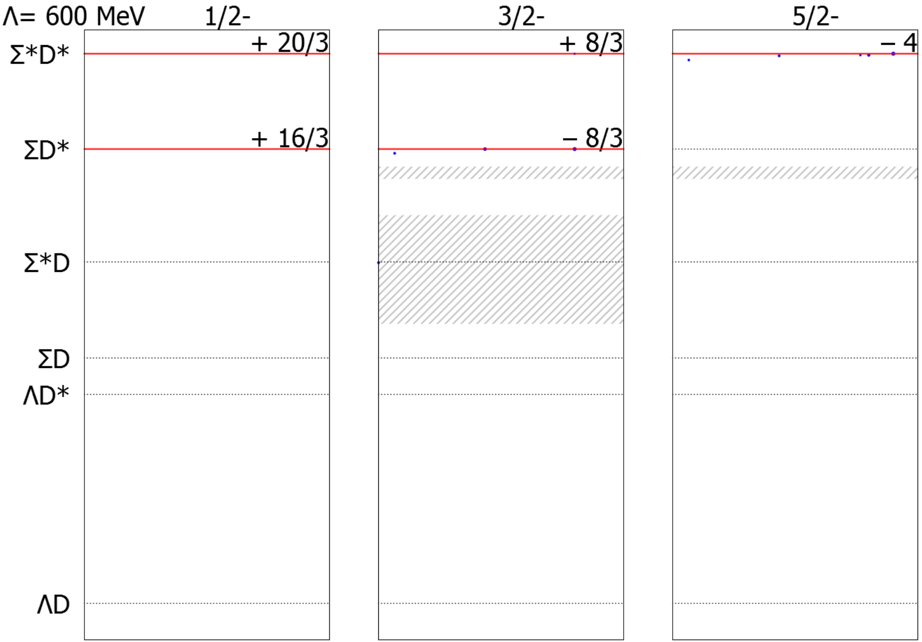
$I(J^P)$	$\Lambda_c \bar{D}$	$\Lambda_c \bar{D}^*$	$\Sigma_c \bar{D}$	$\Sigma_c^* \bar{D}$	$\Sigma_c \bar{D}^*$	$\Sigma_c^* \bar{D}^*$
$\frac{1}{2}\left(\frac{1}{2}^-\right)$	✓	✓	✓		✓	✓
$\frac{1}{2}\left(\frac{3}{2}^-\right)$		✓		✓	✓	✓
$\frac{1}{2}\left(\frac{5}{2}^-\right)$						✓
$\frac{3}{2}\left(\frac{1}{2}^-\right)$			✓		✓	✓
$\frac{3}{2}\left(\frac{3}{2}^-\right)$				✓	✓	✓
$\frac{3}{2}\left(\frac{5}{2}^-\right)$						✓

Hadronic molecule

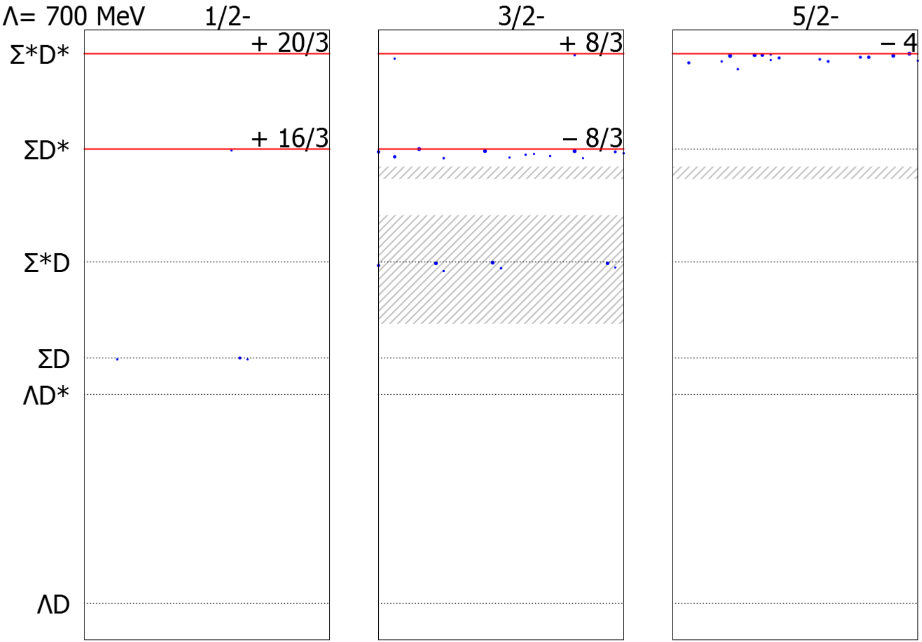
$I(J^P)$	$\Lambda_c \bar{D}$	$\Lambda_c \bar{D}^*$	$\Sigma_c \bar{D}$	$\Sigma_c^* \bar{D}$	$\Sigma_c \bar{D}^*$	$\Sigma_c^* \bar{D}^*$
$\frac{1}{2}\left(\frac{1}{2}^-\right)$	✓	✓	✓		✓	✓
$\frac{1}{2}\left(\frac{3}{2}^-\right)$		✓		✓	$P_c(4450)$	?
$\frac{1}{2}\left(\frac{5}{2}^-\right)$						✓
$\frac{3}{2}\left(\frac{1}{2}^-\right)$			✓		✓	✓
$\frac{3}{2}\left(\frac{3}{2}^-\right)$				✓	✓	✓
$\frac{3}{2}\left(\frac{5}{2}^-\right)$						✓



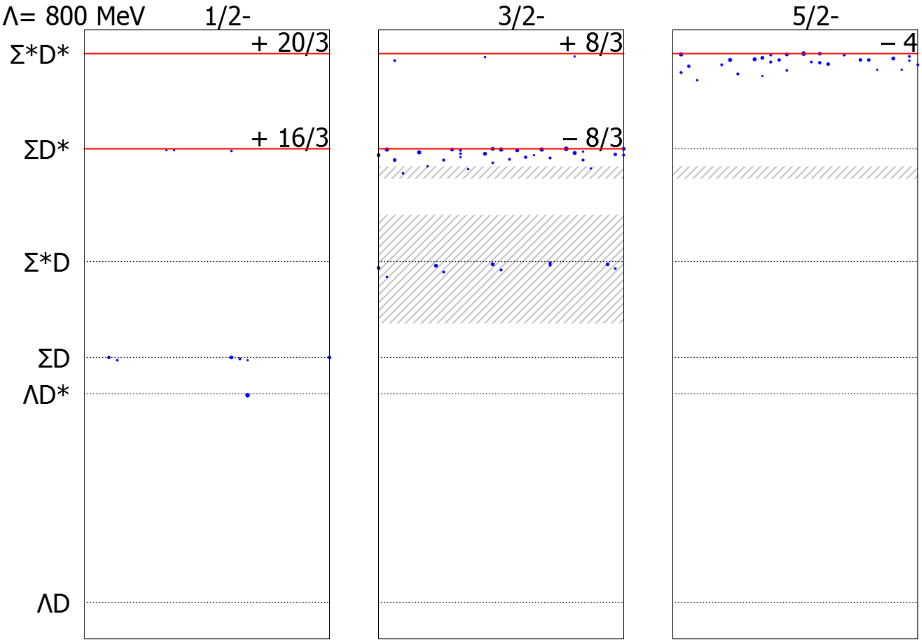
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



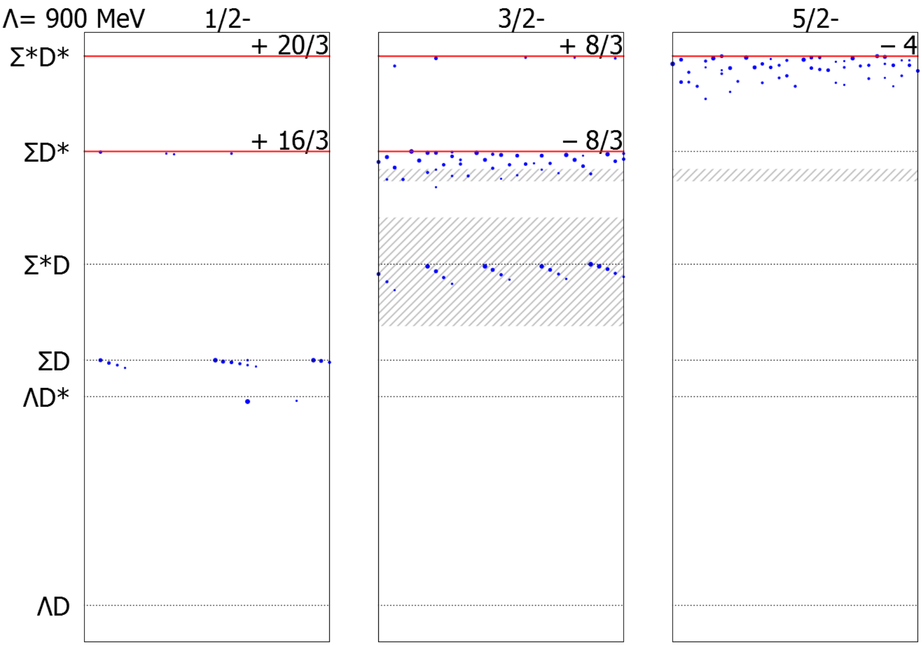
Λ= 600 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



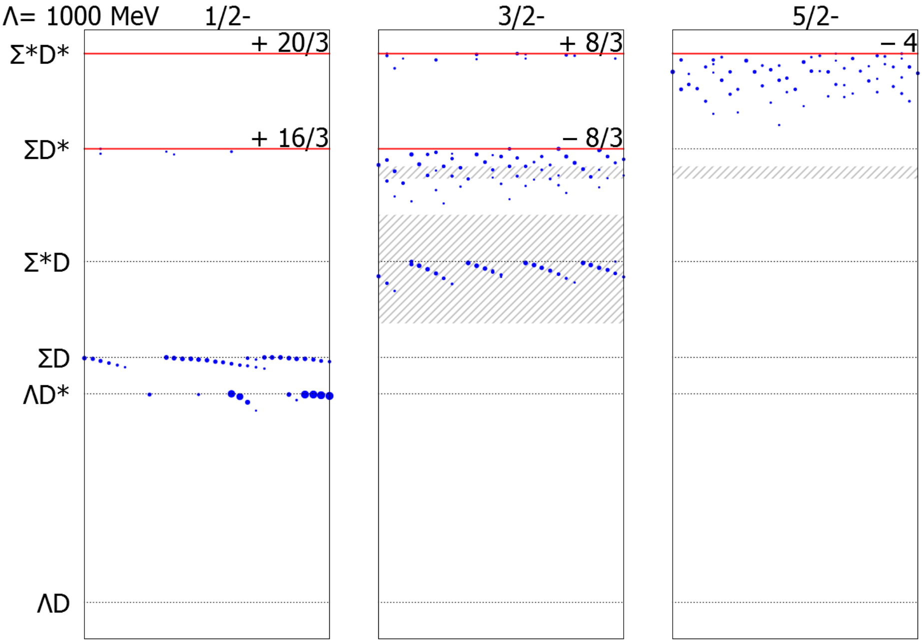
Λ= 700 MeV
1/2-
3/2-
5/2-
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD



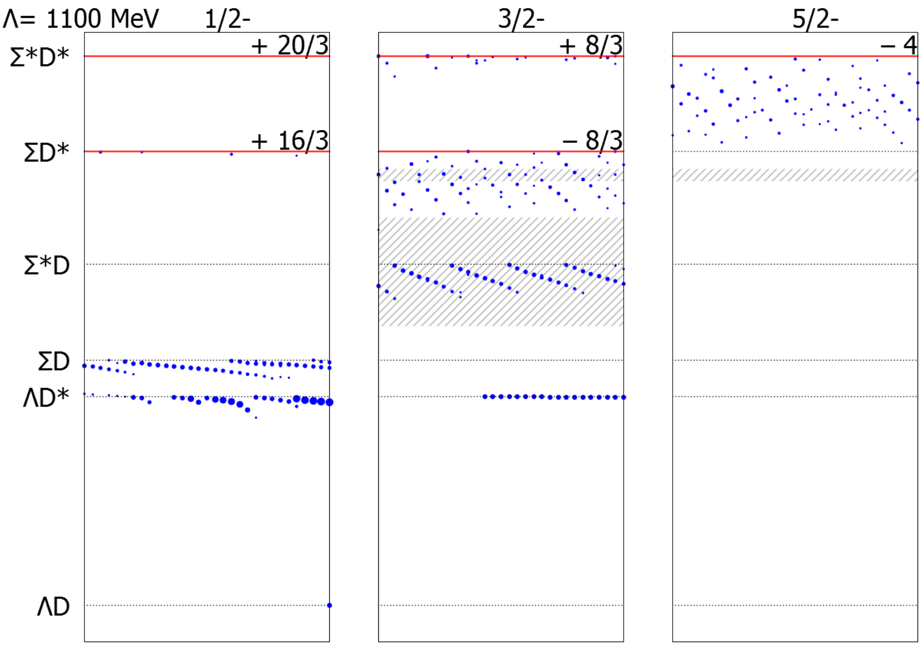
Λ= 800 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



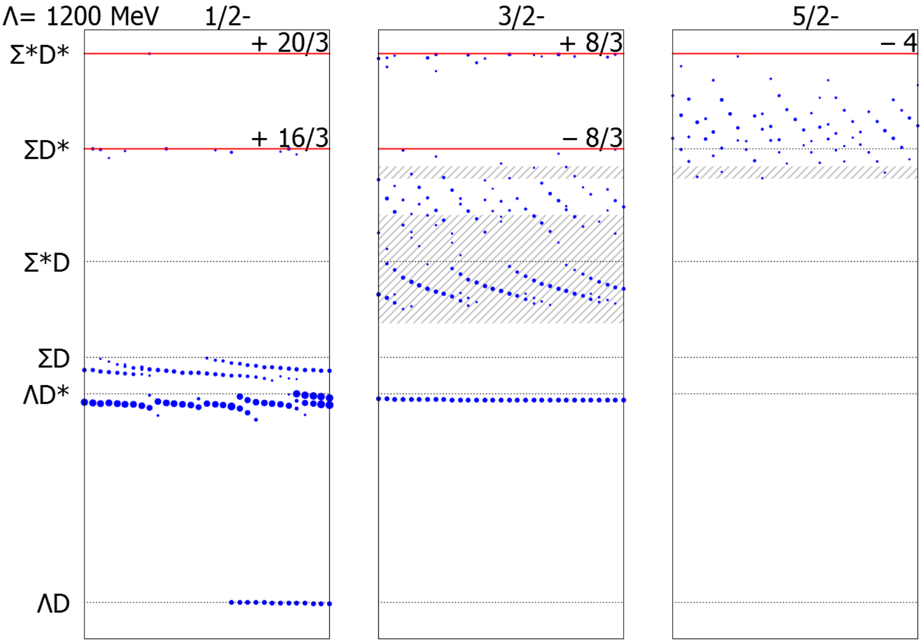
Λ= 900 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



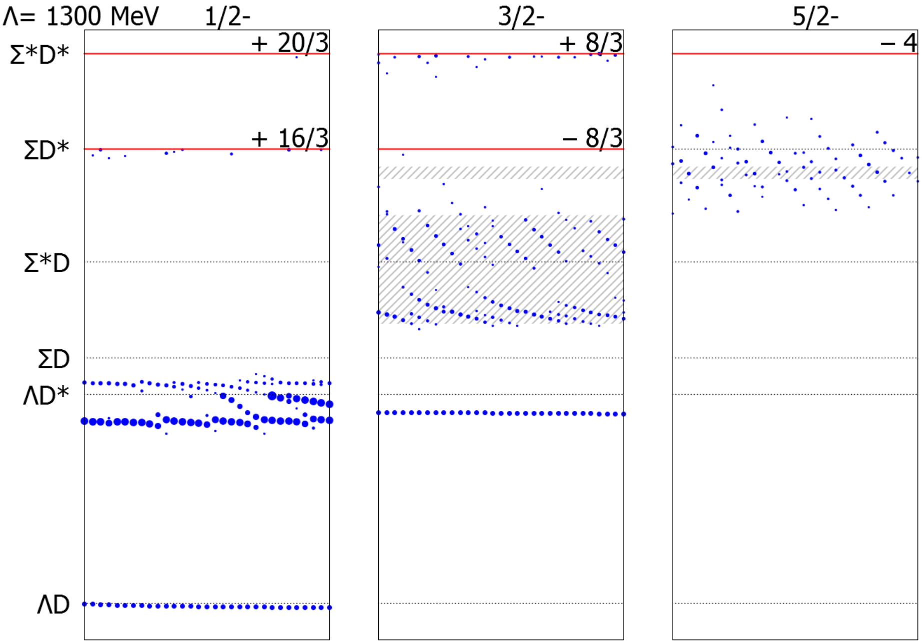
Λ= 1000 MeV
1/2-
3/2-
5/2-
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD



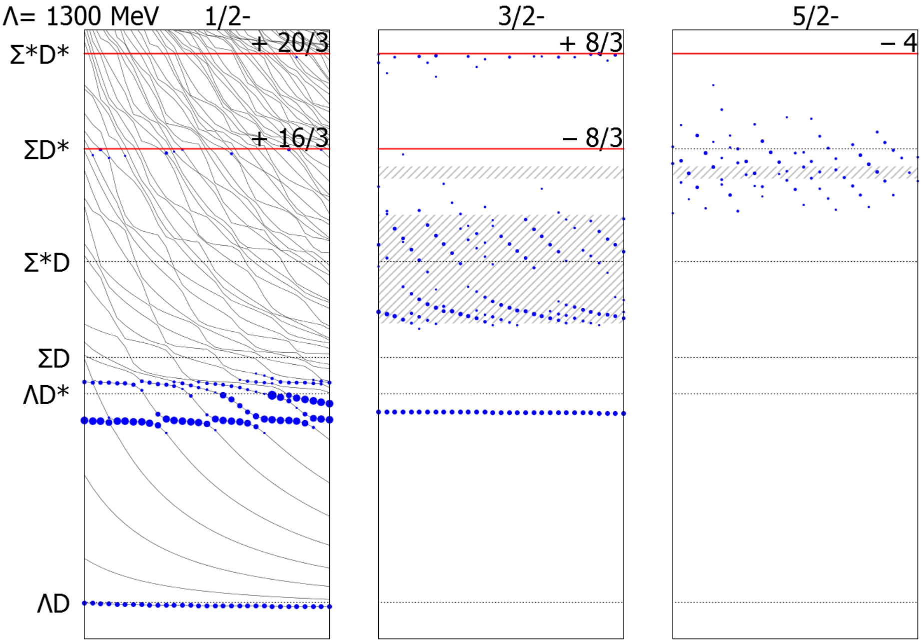
Λ= 1100 MeV
1/2-
3/2-
5/2-
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD



Λ= 1200 MeV
1/2-
3/2-
5/2-
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD

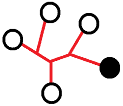
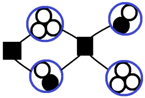
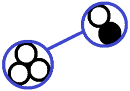


Λ= 1300 MeV
1/2-
3/2-
5/2-
+ 20/3
+ 8/3
− 4
+ 16/3
− 8/3
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD



Λ= 1300 MeV
1/2-
3/2-
5/2-
+ 20/3
+ 8/3
− 4
+ 16/3
− 8/3
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD

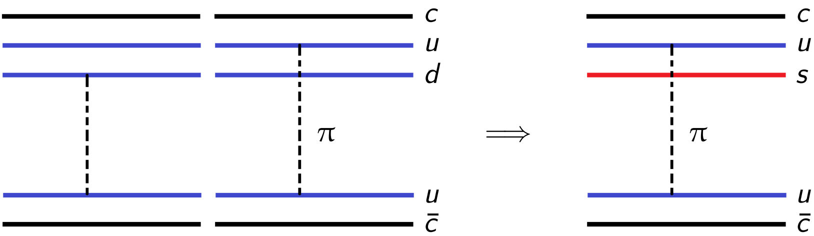
Summary

			
exotic-ness	high!	low	medium
d.o.f.	quarks	hadrons	hadrons
interactions	g exchange	rescattering	π exchange
colour	$(1 \otimes 1) \oplus (8 \otimes 8)$	$(1 \otimes 1)$	$(1 \otimes 1)$
size	compact		extended
masses	model dependent	at thresholds	at thresholds
J^{PC}	all	restricted	restricted
flavours	all	restricted	restricted(I-mix)
channels	most	restricted	HQ restricted
falsifiability	low	medium	high

Backup slides

$\Xi_c^* \bar{D}^*$ molecules

$$\Lambda_c = ((ud)_0 c)_{1/2} \quad \Longrightarrow \quad \Xi_c = ((us)_0 c)_{1/2}$$
$$\Sigma_c = ((ud)_1 c)_{1/2} \quad \Longrightarrow \quad \Xi_c' = ((us)_1 c)_{1/2}$$
$$\Sigma_c^* = ((ud)_1 c)_{3/2} \quad \Longrightarrow \quad \Xi_c^* = ((us)_1 c)_{3/2}$$



The potential matrices (central + tensor) are directly related.

Predict loosely bound $0(5/2^-)$ $\Xi_c^* \bar{D}^*$ state, observable in $\Lambda_b \to J/\psi \Lambda \eta$.

Isospin mixing: $P_c(4380)$ and $P_c(4450)$

$uudc\bar{c}$ comes in two charge combinations $\begin{cases} (udc)(u\bar{c}) = \Sigma_c^+ \bar{D}^0 \\ (uuc)(d\bar{c}) = \Sigma_c^{++} D^- \end{cases}$

Isospin-conserving interactions would produce $|I, I_3\rangle$ eigenstates,

$$\begin{pmatrix} |\frac{1}{2}, \frac{1}{2}\rangle \\ |\frac{3}{2}, \frac{1}{2}\rangle \end{pmatrix} = \begin{pmatrix} -\sqrt{\frac{1}{3}} & \sqrt{\frac{2}{3}} \\ \sqrt{\frac{2}{3}} & \sqrt{\frac{1}{3}} \end{pmatrix} \begin{pmatrix} |\Sigma_c^+ \bar{D}^0\rangle \\ |\Sigma_c^{++} D^-\rangle \end{pmatrix}$$

but only if the masses $\Sigma_c^+ = \Sigma_c^{++}$ and $\bar{D}^0 = D^-$.

Otherwise, isospin is not a good quantum number.

Isospin mixing: $P_c(4380)$ and $P_c(4450)$

$$\Sigma_c^{*+}\bar{D}^0 = 4382.3 \pm 2.4 \qquad \Sigma_c^{+}\bar{D}^{*0} = 4459.9 \pm 0.5$$

$$\Sigma_c^{*++}D^- = 4387.5 \pm 0.7 \qquad \Sigma_c^{++}D^{*-} = 4464.24 \pm 0.23$$

Isospin mixing: $P_c(4380)$ and $P_c(4450)$

$$P_c(4380) = 4380 \pm 8 \pm 29 \qquad P_c(4450) = 4449 \pm 1.7 \pm 2.5$$

$$\Sigma_c^{*+}\bar{D}^0 = 4382.3 \pm 2.4 \qquad \Sigma_c^{+}\bar{D}^{*0} = 4459.9 \pm 0.5$$

$$\Sigma_c^{*++}D^- = 4387.5 \pm 0.7 \qquad \Sigma_c^{++}D^{*-} = 4464.24 \pm 0.23$$

Isospin mixing: $P_c(4380)$ and $P_c(4450)$

$$\begin{aligned} P_c(4380) &= 4380 \pm 8 \pm 29 \\ \Sigma_c^{*+}\bar{D}^0 &= 4382.3 \pm 2.4 \\ \Sigma_c^{*++}D^- &= 4387.5 \pm 0.7 \end{aligned} \qquad \begin{aligned} P_c(4450) &= 4449 \pm 1.7 \pm 2.5 \\ \Sigma_c^{+}\bar{D}^{*0} &= 4459.9 \pm 0.5 \\ \Sigma_c^{++}D^{*-} &= 4464.24 \pm 0.23 \end{aligned}$$

The P_c states have mixed isospin:

$$|P_c\rangle = \cos\phi|\tfrac{1}{2},\tfrac{1}{2}\rangle + \sin\phi|\tfrac{3}{2},\tfrac{1}{2}\rangle$$

Isospin mixing: $P_c(4380)$ and $P_c(4450)$

$$\begin{aligned} P_c(4380) &= 4380 \pm 8 \pm 29 \\ \Sigma_c^{*+}\bar{D}^0 &= 4382.3 \pm 2.4 \\ \Sigma_c^{*++}D^- &= 4387.5 \pm 0.7 \end{aligned} \qquad \begin{aligned} P_c(4450) &= 4449 \pm 1.7 \pm 2.5 \\ \Sigma_c^{+}\bar{D}^{*0} &= 4459.9 \pm 0.5 \\ \Sigma_c^{++}D^{*-} &= 4464.24 \pm 0.23 \end{aligned}$$

The P_c states have mixed isospin:

$$|P_c\rangle = \cos\phi|\tfrac{1}{2},\tfrac{1}{2}\rangle + \sin\phi|\tfrac{3}{2},\tfrac{1}{2}\rangle$$

They should decay also into $J/\psi\Delta^+$ and $\eta_c\Delta^+$, with weights:

$$J/\psi p : J/\psi\Delta^+ : \eta_c\Delta^+ = 2\cos^2\phi : 5\sin^2\phi : 3\sin^2\phi \quad [P_c(4380)]$$
$$J/\psi p : J/\psi\Delta^+ : \eta_c\Delta^+ = \cos^2\phi : 10\sin^2\phi : 6\sin^2\phi \quad [P_c(4450)]$$

Isospin mixing: predicted $5/2^-$ states

$\Sigma_c^* \bar{D}^*$ $1/2(5/2^-)$

$$\Sigma_c^{*+} \bar{D}^{*0} = 4524.4 \pm 2.4$$
$$\Sigma_c^{*++} D^{*-} = 4528.2 \pm 0.7$$

Mixed isopsin:
$|P\rangle = \cos\phi|\frac{1}{2},\frac{1}{2}\rangle + \sin\phi|\frac{3}{2},\frac{1}{2}\rangle$

Decays:
$\to J/\psi p$: D-wave, spin flip
Reason for absence at LHCb?

$\to J/\psi \Delta$: S-wave, spin cons.
$\implies I = 3/2$ decay enhanced.

Isospin mixing: predicted $5/2^-$ states

$\Sigma_c^* \bar{D}^*$ $1/2(5/2^-)$

$$\Sigma_c^{*+} \bar{D}^{*0} = 4524.4 \pm 2.4$$
$$\Sigma_c^{*++} D^{*-} = 4528.2 \pm 0.7$$

Mixed isopsin:
$|P\rangle = \cos\phi|\frac{1}{2}, \frac{1}{2}\rangle + \sin\phi|\frac{3}{2}, \frac{1}{2}\rangle$

Decays:
$\rightarrow J/\psi p$: D-wave, spin flip
Reason for absence at LHCb?

$\rightarrow J/\psi \Delta$: S-wave, spin cons.
$\Longrightarrow$ $I = 3/2$ decay enhanced.

$\Xi_c^* \bar{D}^*$ $0(5/2^-)$

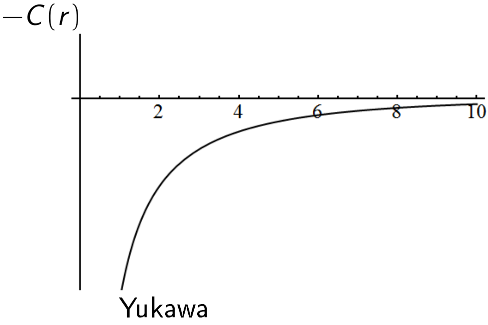
$$\Xi_c^{*0} \bar{D}^{*0} = 4652.9 \pm 0.6$$
$$\Xi_c^{*+} D^{*-} = 4656.2 \pm 0.7$$

Mixed isopsin:
$|P\rangle = \cos\phi|0, 0\rangle + \sin\phi|1, 0\rangle$

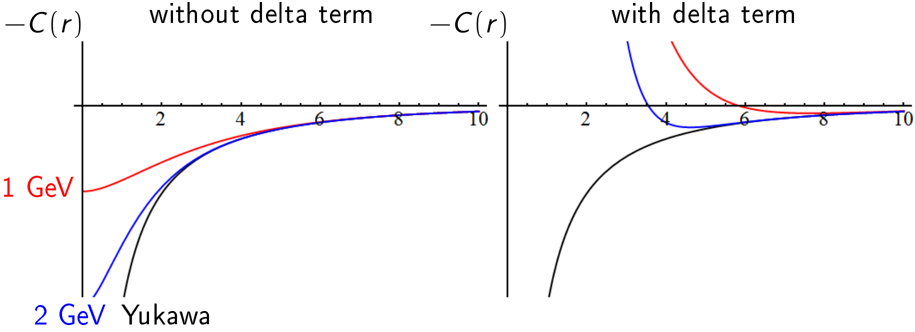
Decays:
$\rightarrow J/\psi \Lambda$: D-wave, spin flip
e.g. $\Lambda_b^0 \rightarrow J/\psi \Lambda \eta$, $J/\psi \Lambda \phi$

$\rightarrow J/\psi \Sigma^*$: S-wave, spin cons.
$\Longrightarrow$ $I = 1$ decay enhanced.

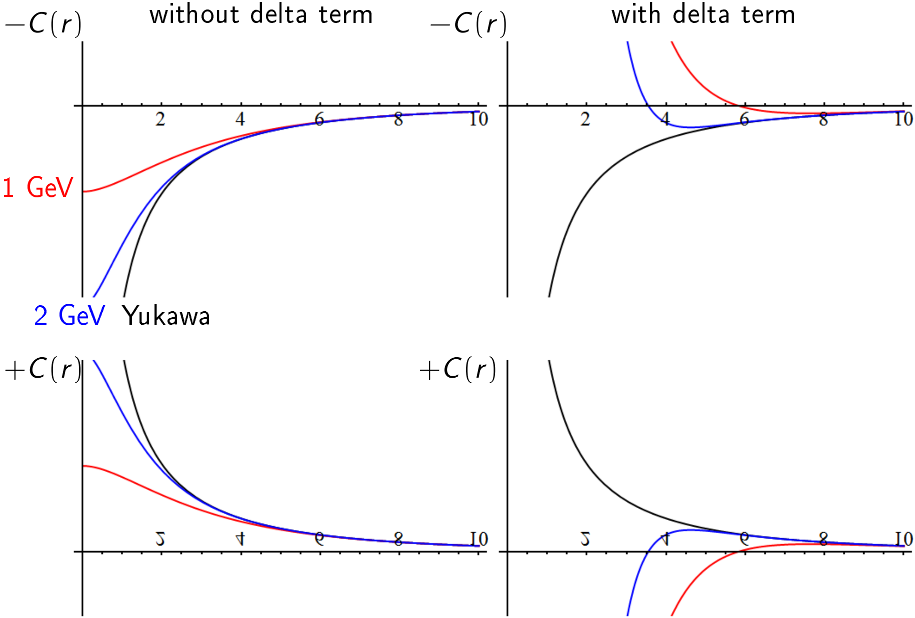
Pion exchange: central potential

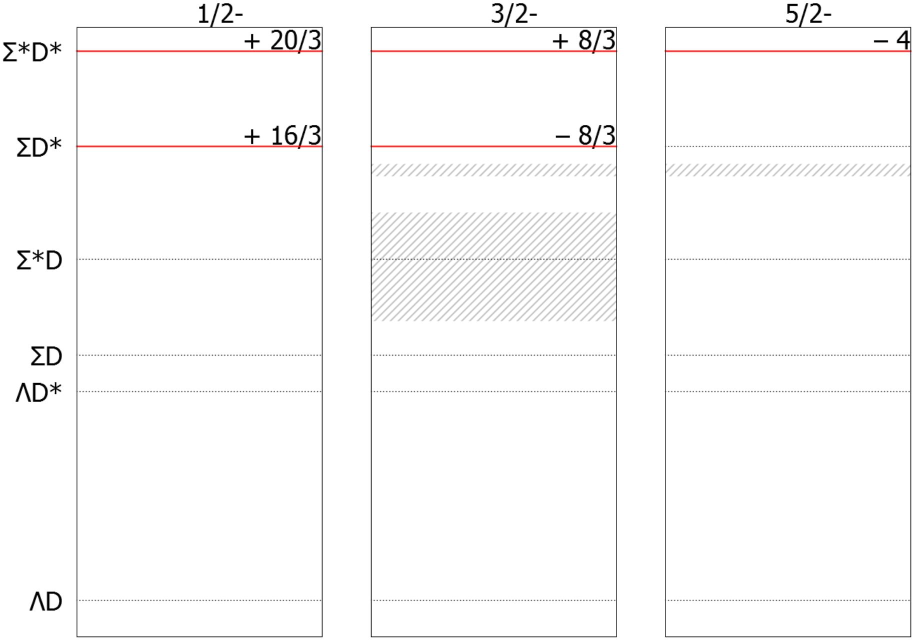


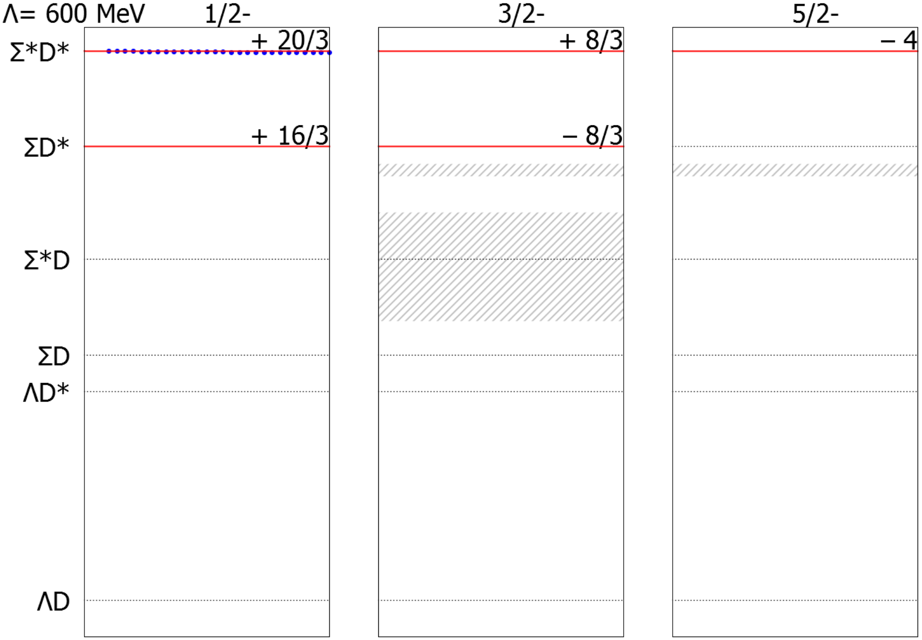
Pion exchange: central potential



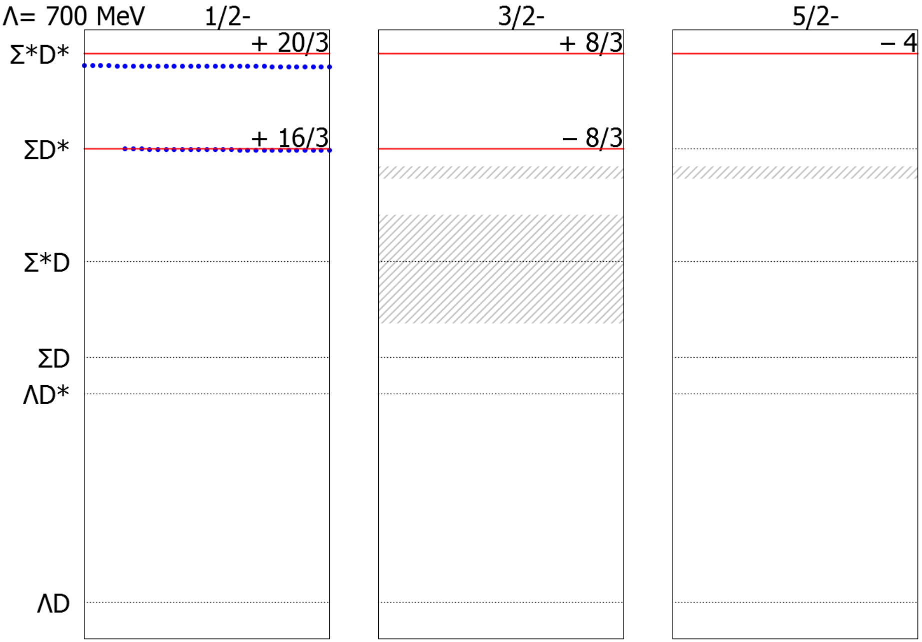
Pion exchange: central potential



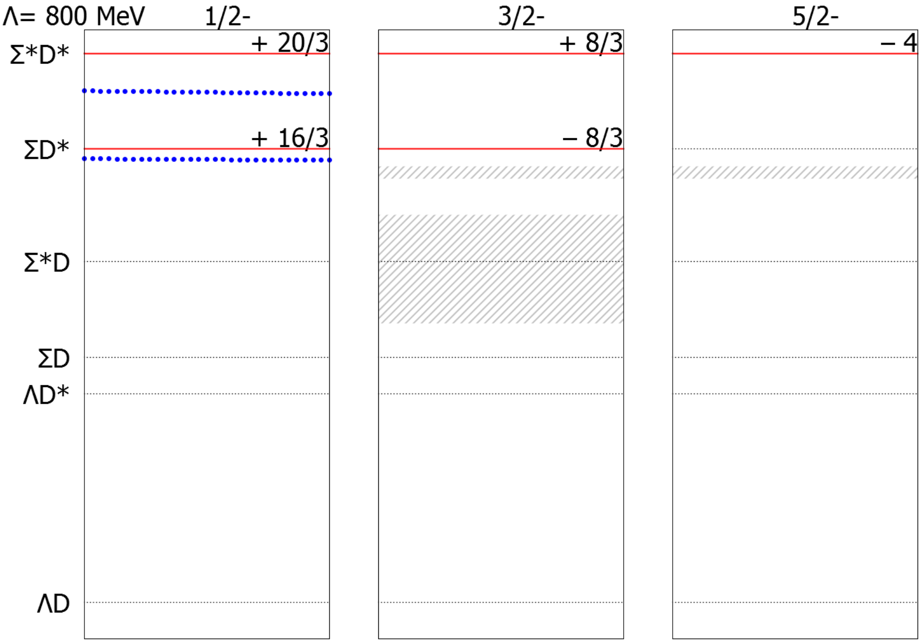

1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4

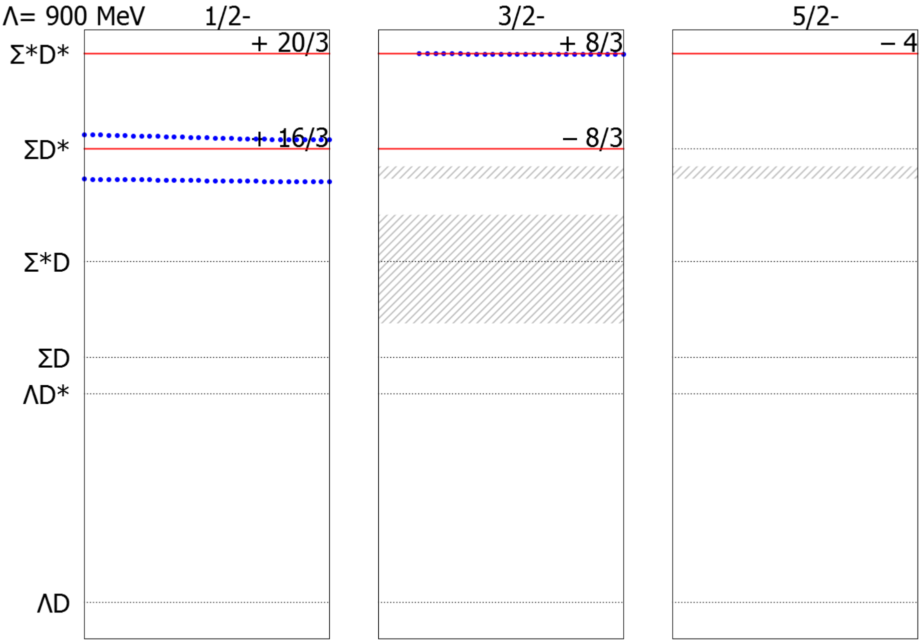


Λ= 600 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4

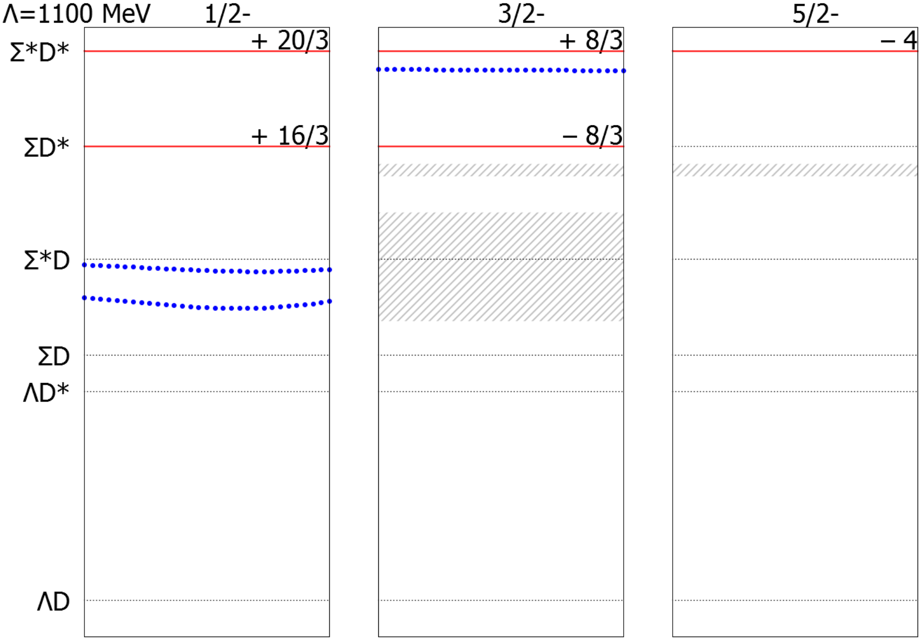


Λ= 700 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4

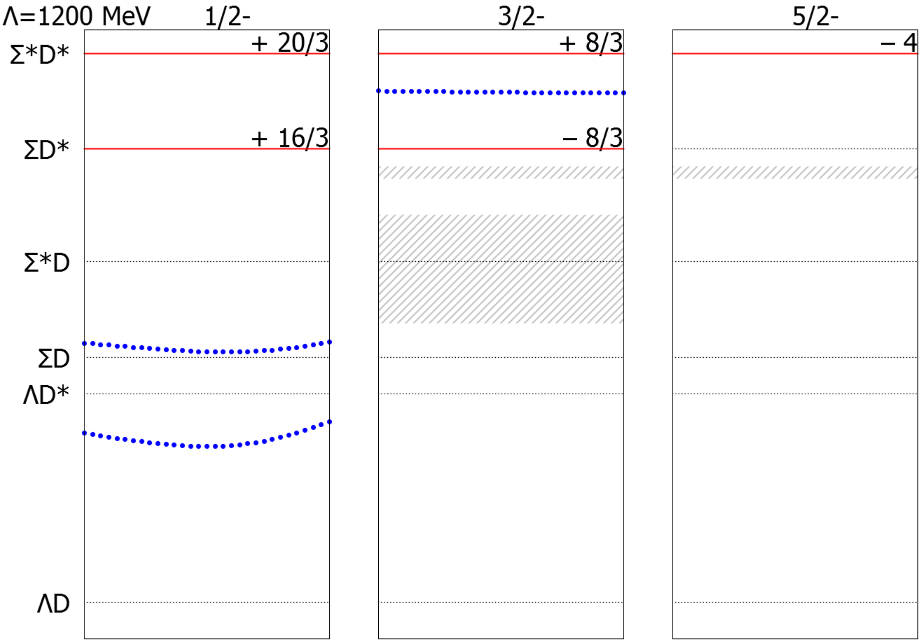

Λ= 800 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



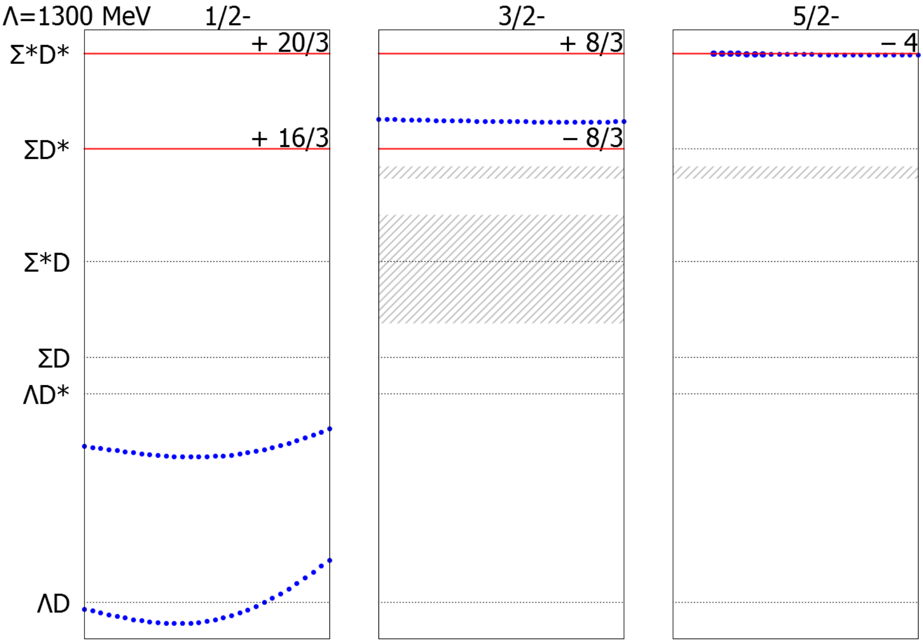
Λ= 900 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



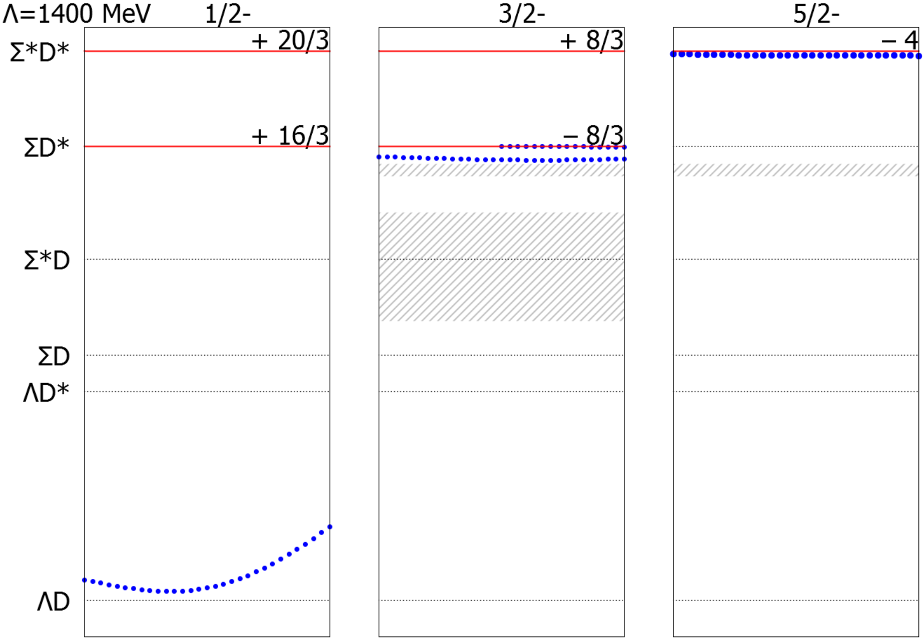
Λ=1100 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



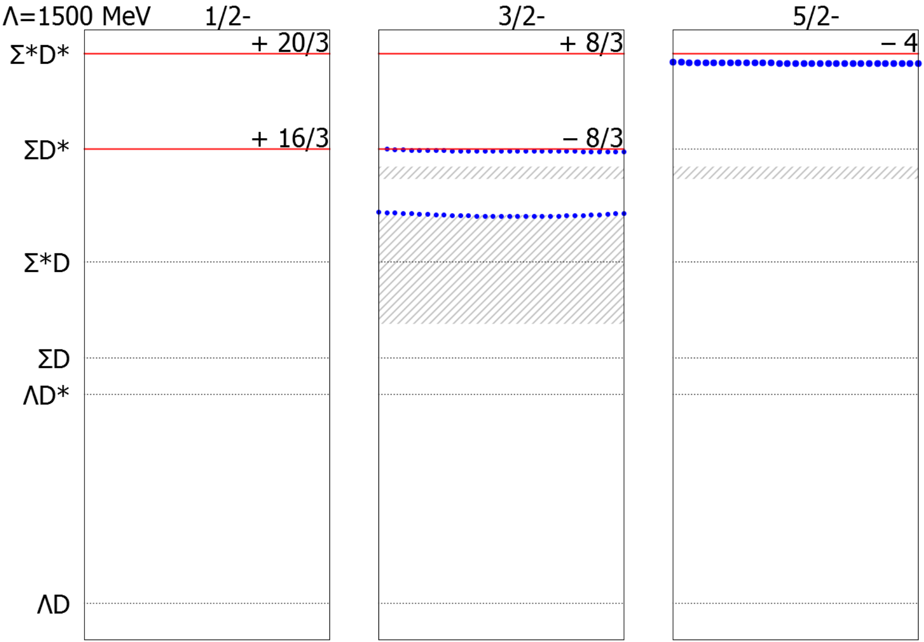
Λ=1200 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



Λ=1300 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



Λ=1400 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4



Λ=1500 MeV
1/2-
3/2-
5/2-
Σ*D*
ΣD*
Σ*D
ΣD
ΛD*
ΛD
+ 20/3
+ 16/3
+ 8/3
− 8/3
− 4