Are narrow unflavoured mesons a signature of new phyiscs ?

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Résumé

The present work collects data from experiments to support the existence of narrow mesons. A selected part of the scatterplot from $\bar{p}p$ annihilation at rest into two γ's : M(γ3, γ4) = f (M(γ1, γ2)) is reported for the first time. *We suggest that they are produced by two quark clusters and propose a simple one-parameter mass formula.*

Introduction

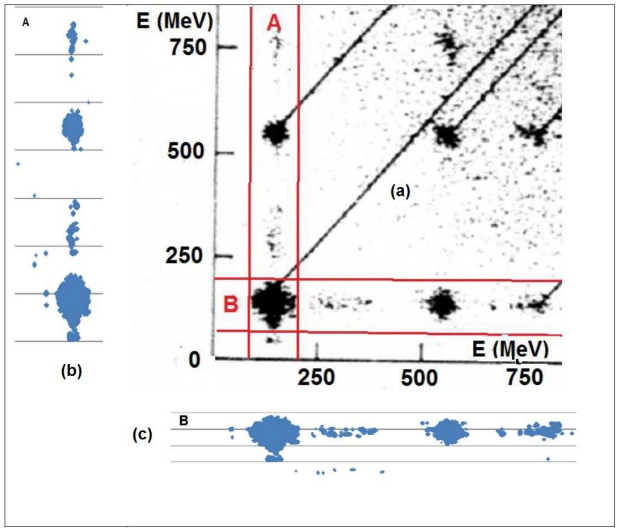
- Experimental works have been dedicated to the search of narrow, weakly excited, low mass unflavoured mesons. Besides these works, a large number of data, studied for different purposes, exhibit also small structures in their spectra.
- These structures are observed in leptonic, as well as in hadronic reactions, *but they were not discussed by the authors in detail.* They hardly pass the 5σ criterium but appear in different high resolution, high statistics experiments, with different probes.
- The present work collects data from dedicated - or not - experiments, and shows also old data never used to support the existence of narrow mesons. The nice concordance of all various masses, strengthen the opinion that they are genuine.
- We suggest to associate these exotic masses to two quark clusters using a one parameter mass formula.

$p\bar{p}$ annihilation at rest : LEAR

Crystal Barrel C. Amsler, Reviews of Modern Physics, **70**, 1293 (1998)

- Truncated spectrum read on scatterplot : no statistical information.

  $M(\gamma 3, \gamma 4) = f\,(M(\gamma 1, \gamma 2))$
- Two ranges A and B, selected, and scanned, giving rise to the two blue areas.
- The blobs are wider when the peaks correponding to the particles are larger.
- The peaks are "simulated" by the correponding number of dark bits.



- Black lines identify $\eta\pi^0$, $\pi^0\pi^0$, $\eta\eta$, $\eta\omega$, $\omega\pi^0$

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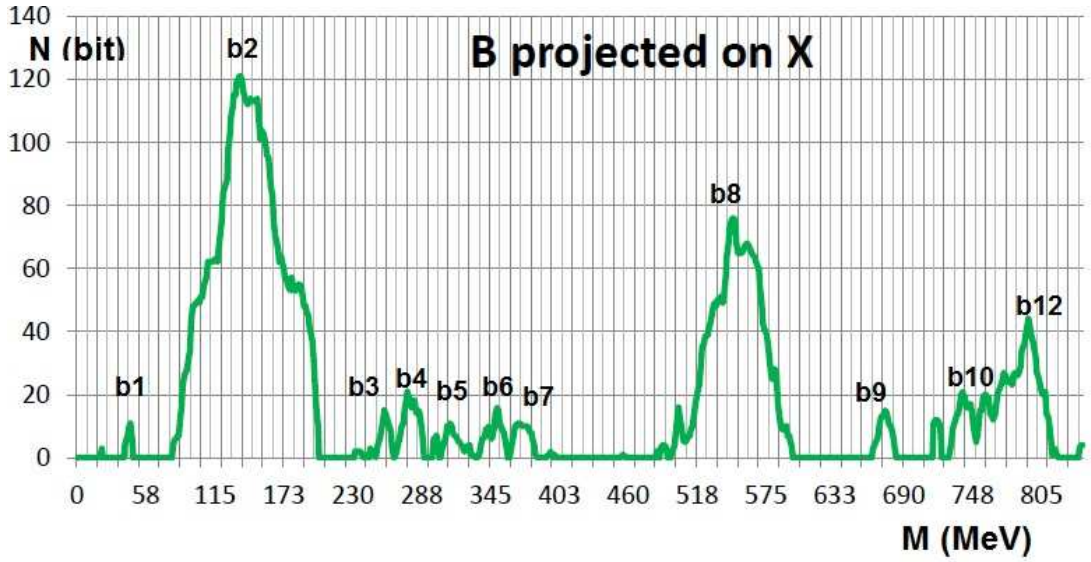
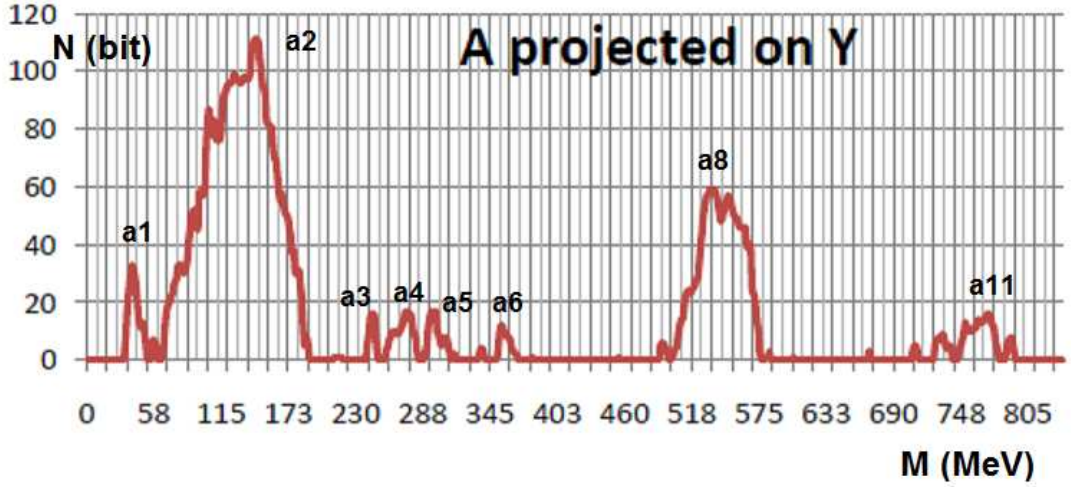
$p\bar{p}$ annihilation at rest (LEAR) : projections



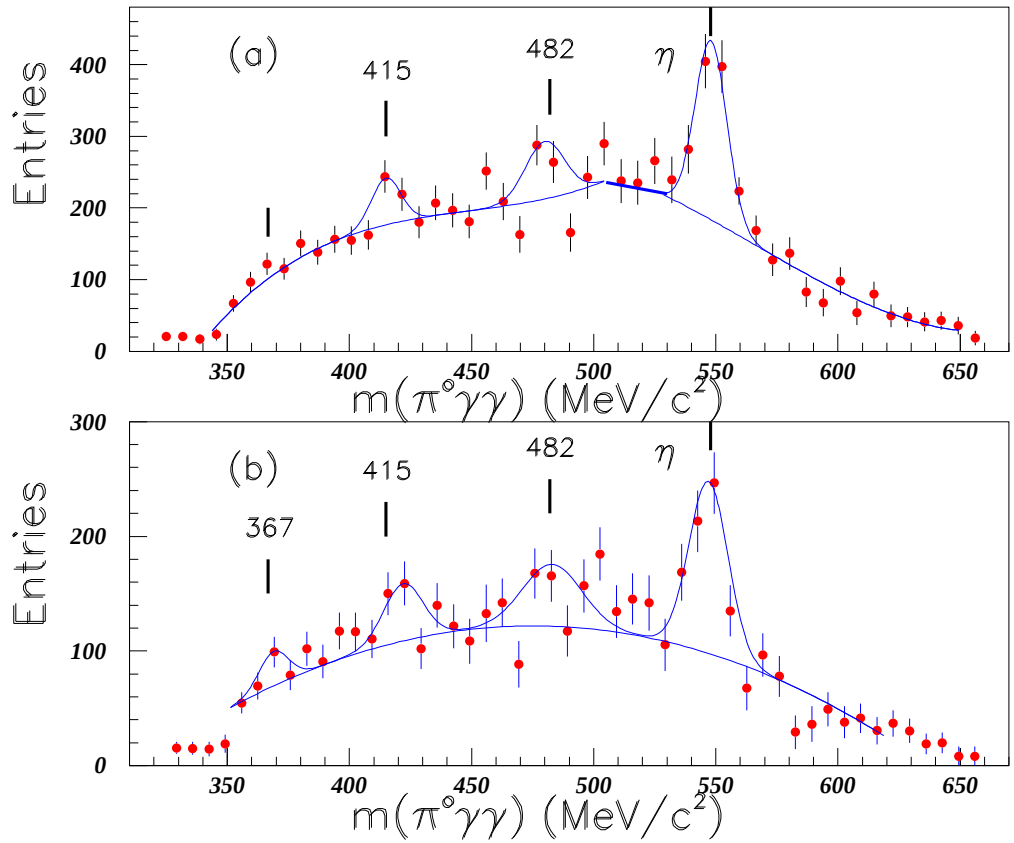


	1	2	3	4	5	6	7	8	9	10	11	12
a	42	138	246	275	296	355		544			762	
b	45	142	255	280	313	350	370	552	676	742		795
OLD	45	137	252	275	310	347	367	550	675		754.7	

The $\eta \to \pi^0\gamma\gamma$ invariant mass

B.M.K. Nefkens *et al.* arXiv :1405.4904v1 [hep-ex]
Crystal Ball/TAPS , Mainz Microtron, rare decay $\eta \to \pi^0\gamma\gamma$.
Not well defined structures, 'right' masses.

Full range of $m^2(\gamma\gamma)$

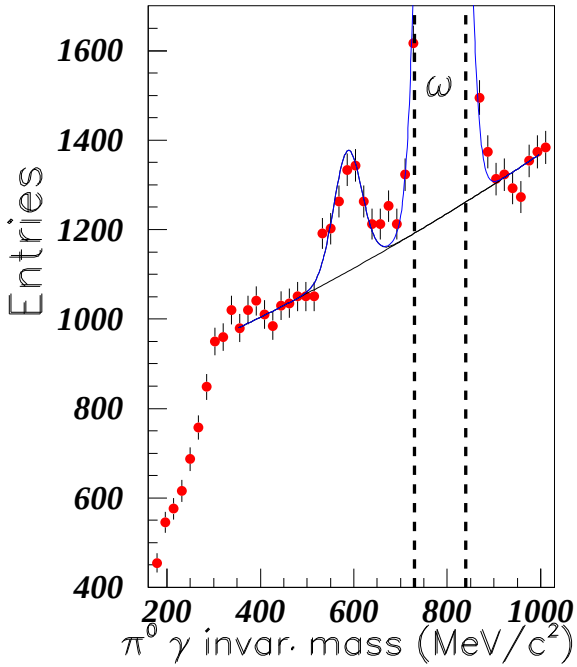


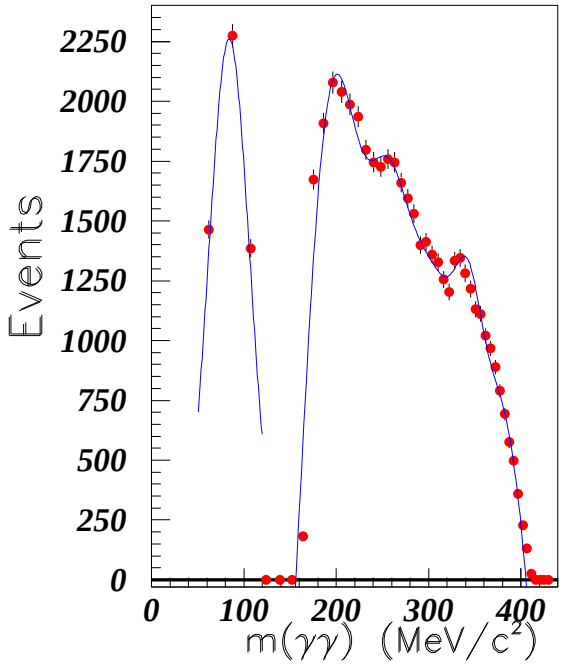
Same, except a cut on the cluster effective radius.

Previously extracted narrow low mass exotic mesons are marked.

Other Reactions with Crystal Ball

$p\bar{p} \rightarrow \pi^0\gamma$ at p_p=1940 MeV/c (LEAR)
A.Abele *et al.*, EPJC**12**, 429 (2000).
$M_{\pi^0\gamma}$ =587[585] MeV





AGS Crystal Ball
S. Prakhov *et al.* PRC**78** 015206 (2008).
$\pi^- p \rightarrow \pi^0\gamma\gamma$ ($\eta \rightarrow \pi^{0\gamma\gamma}$)
$M_{\gamma\gamma}$=84[81.3], 190[194], 255[251], and 343[349] MeV
Structures not commented by the authors

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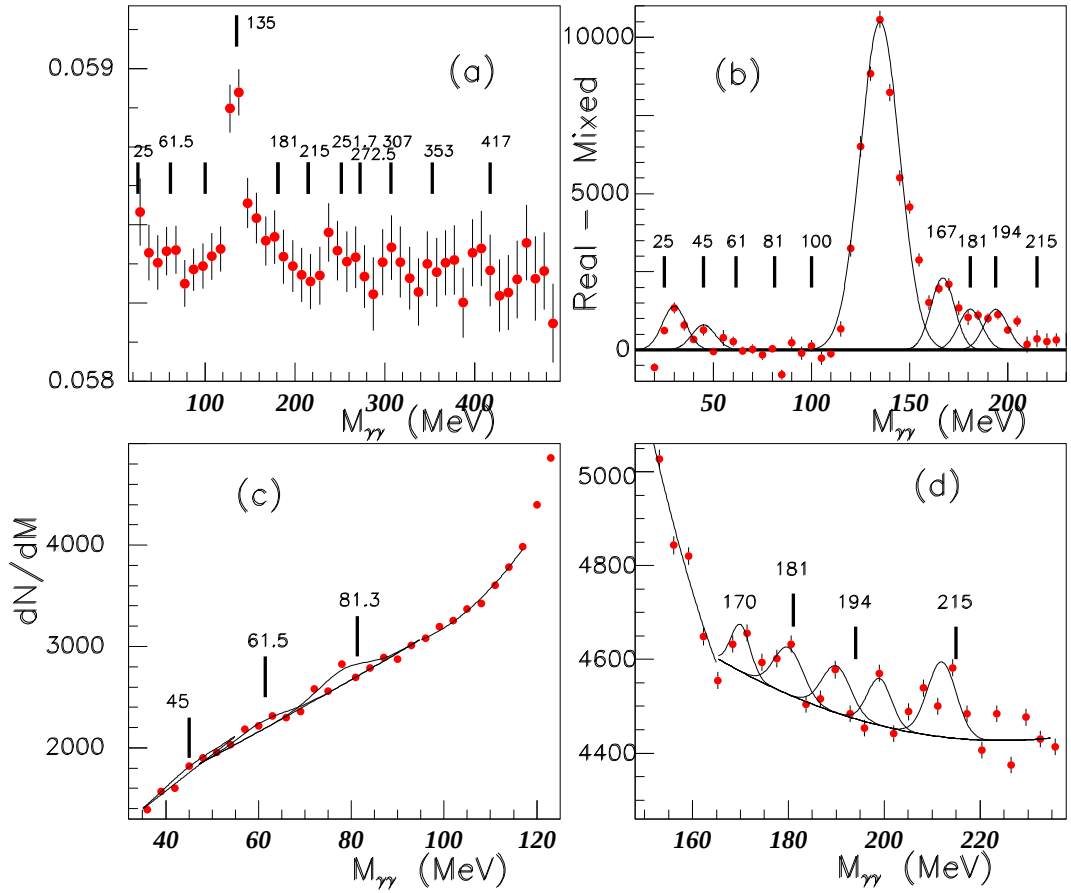
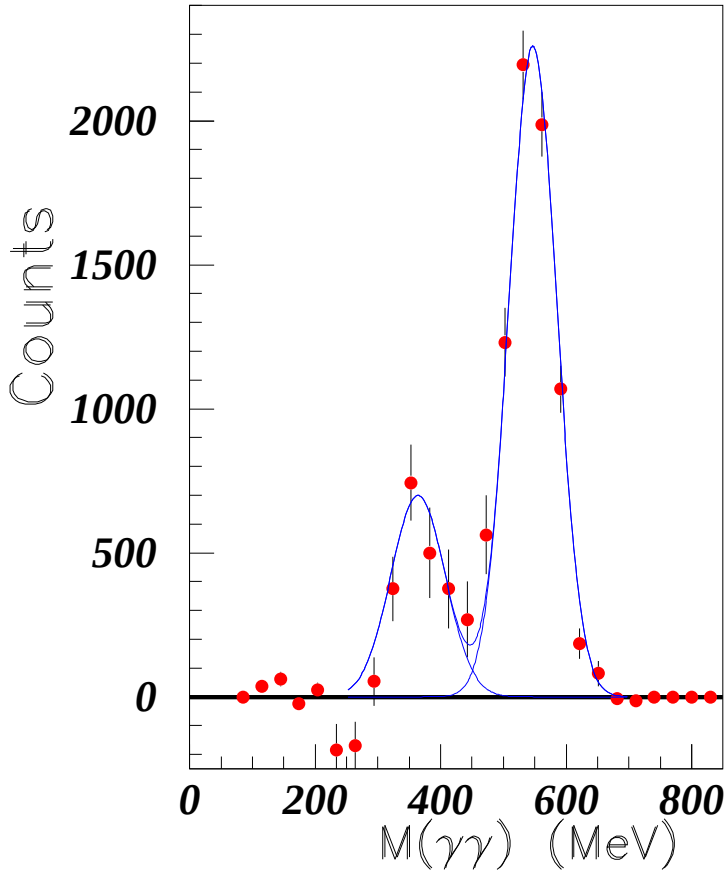
$M_{\gamma\gamma}$ in high energy heavy ion reactions



(a) Pb-Pb events (Alice) Physics Performance Report, Volume II, Phys. G. :Nucl. Part. Phys. 32, 1295 (2006).
(b) Pb-Pb events Alice/PHOS M. Ippolitov and A. Vasil'ev, CALOR2004, www.pg.infn.it/calor2004/program/.../ippolitov.pdf.
(c) and (d) ^{32}S + Au CERN(SPS) (Saphir), F. Berger *et al.*, Nucl.Instr.Meth.Phys.Res. A321, 152 (1992).

Data taken for detector calibration.

Other reactions



dC interaction at the JINR Nuclotron

Kh.U. Abraamyan *et al.*, PRC **80**, 034001 (2009).

$M_{\gamma\gamma}$= 360[366] MeV (S.D.= 4.7)

not observed in pC reaction

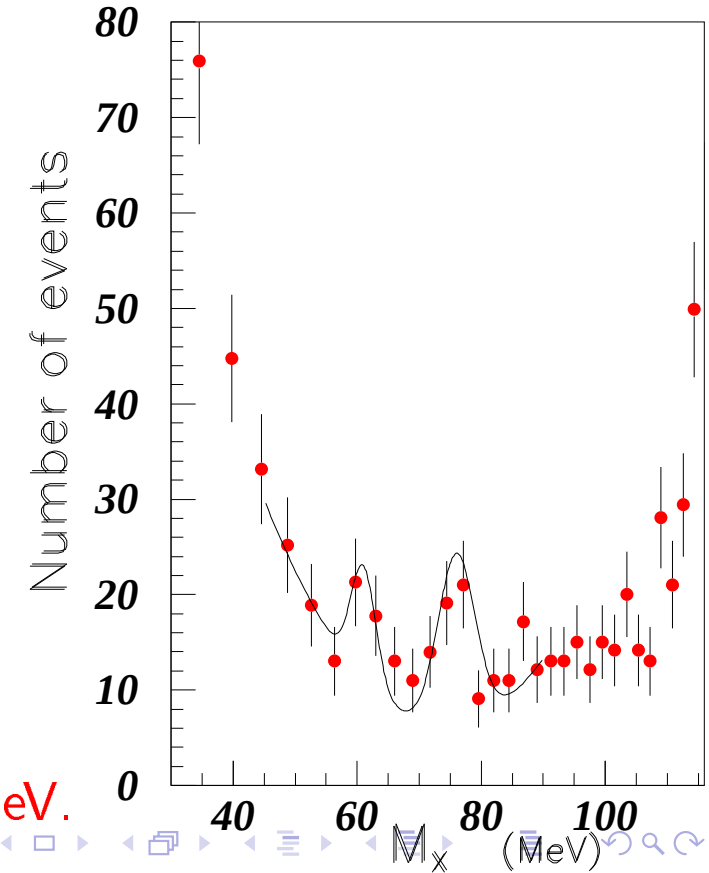
Missing mass of the reaction

$pp \rightarrow ppX$

measured at Uppsala

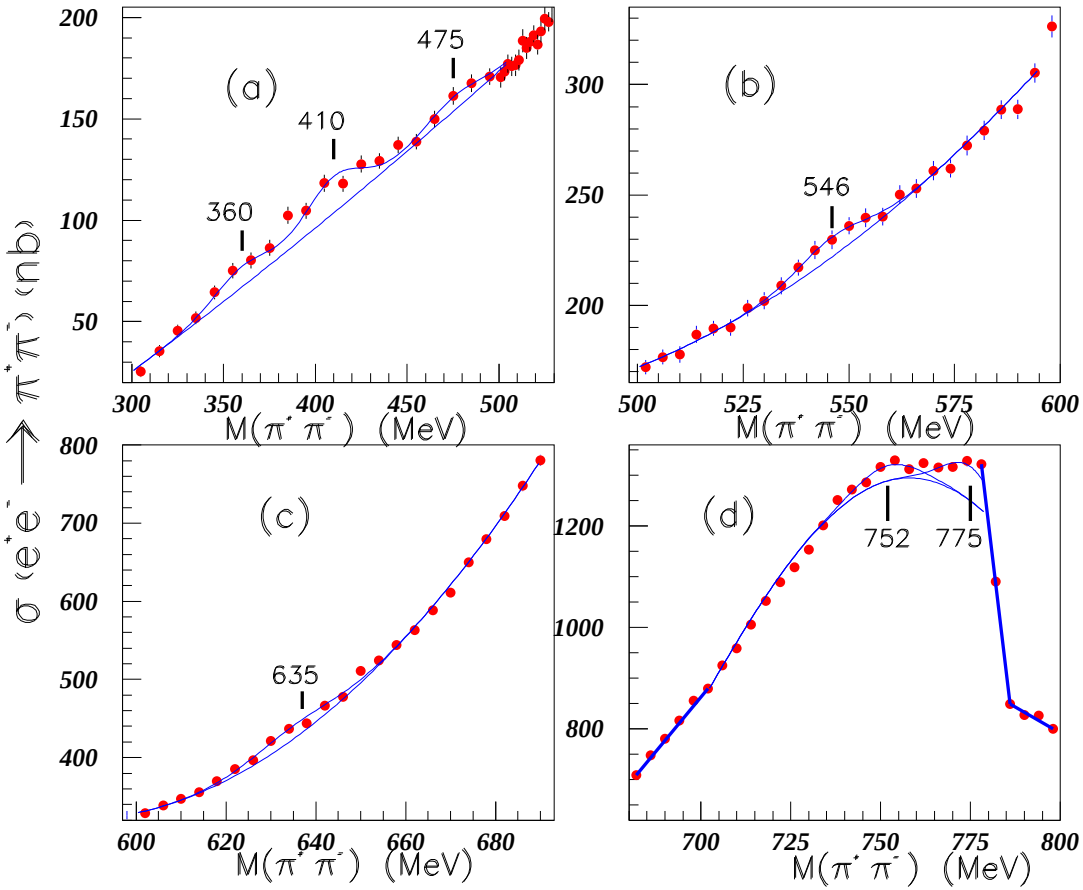
A. Johansson and C. Wilkin, PLB**673** (2009) 5.

M_X = 61[62] MeV and 76[80] MeV.



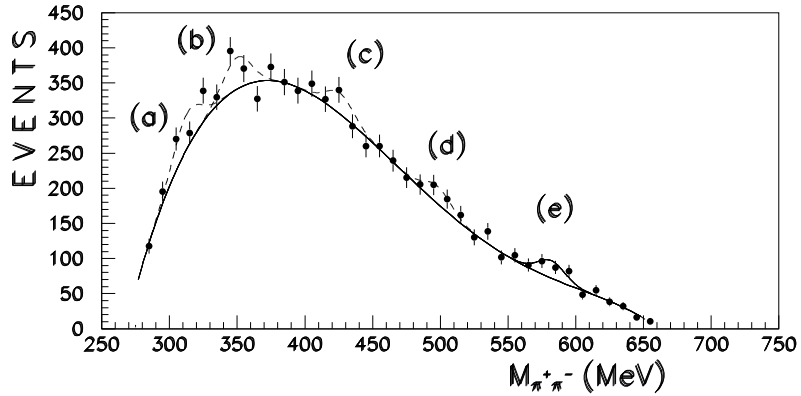
The reaction $e^+e^- \rightarrow \pi^+\pi^-$ (BaBaR) : $M(\pi^+\pi^-)$

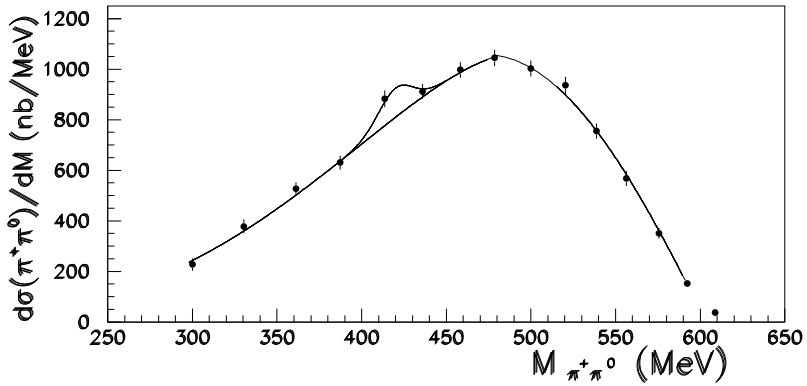
no quarks in initial state

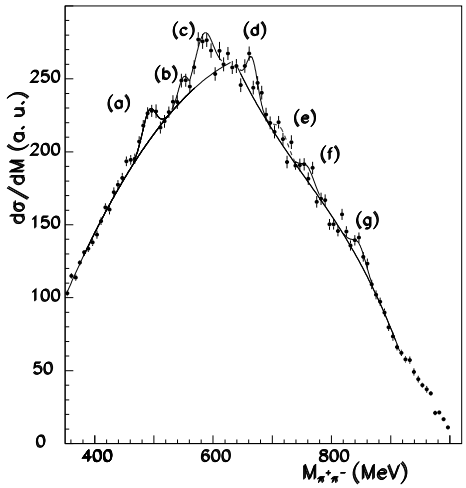


Cross section of the $e^+e^- \rightarrow \pi^+\pi^-$ reaction : precise data, small binning. B. Aubert *et al.*, (BABAR Collaboration) Phys. Rev. Lett. 103, 231801 (2009)

Invariant mass $M_{\pi\pi}$







$N_{ev}(M_{\pi^+\pi^-})$

$\gamma p \rightarrow p\pi^+\pi^-$

$300 \leq E_\gamma \leq 5800$ MeV.

(DESY), H2 bubble chamber

(Aachen-Berlin-Bonn-Hamburg-Heidelberg-München Collaboration).

PRL 175 (1968) 1669

$\sigma(M_{\pi^+\pi^0})$

$\gamma p \rightarrow n\pi^+\pi^0$

$611 \leq E_\gamma \leq 818$ MeV.

(MAMI)

$M_{\pi^+\pi^0}$=417 MeV [415].

$N_{ev}(M_{\pi^+\pi^-})$

$pp \rightarrow pp\pi^+\pi^-$

$\cos(\theta^{CM}) \leq 0.6$

DISTO (Saturne)

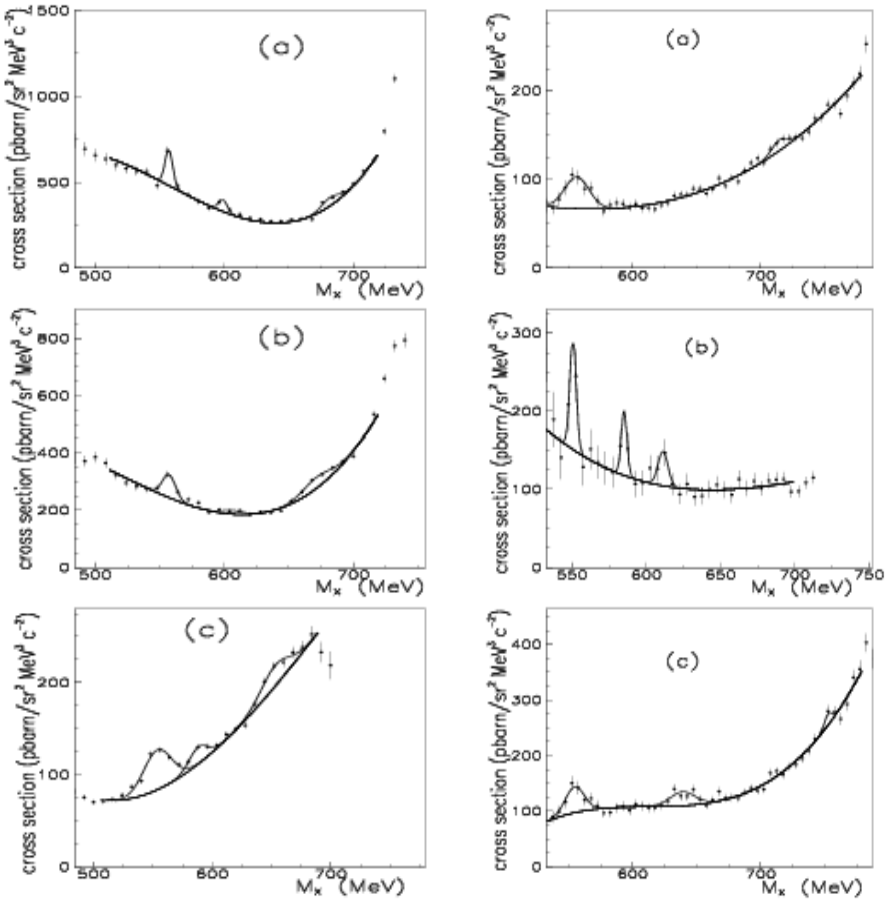
PRL 89 (2002) 092001

(a)	b)	(c)	(d)	(e)	(f)	(g)
488	550	585	670	715	760	847
484.7	549.7	584.7	675.2	700	754.7	

M_X from $pp \rightarrow ppX$ reaction SPES3 (Saturne)

B. Tatischeff *et al.* Phys. Rev. C**62**, 054001 (2000)

T_p=1805 MeV T_p=2100 MeV



- Both protons detected in the same spectrometer
- Several spectrometer angles at each energy

$\theta = 0^0, 3^0, 9^0$ 9^0

forward, backward, M_{pp} selec.

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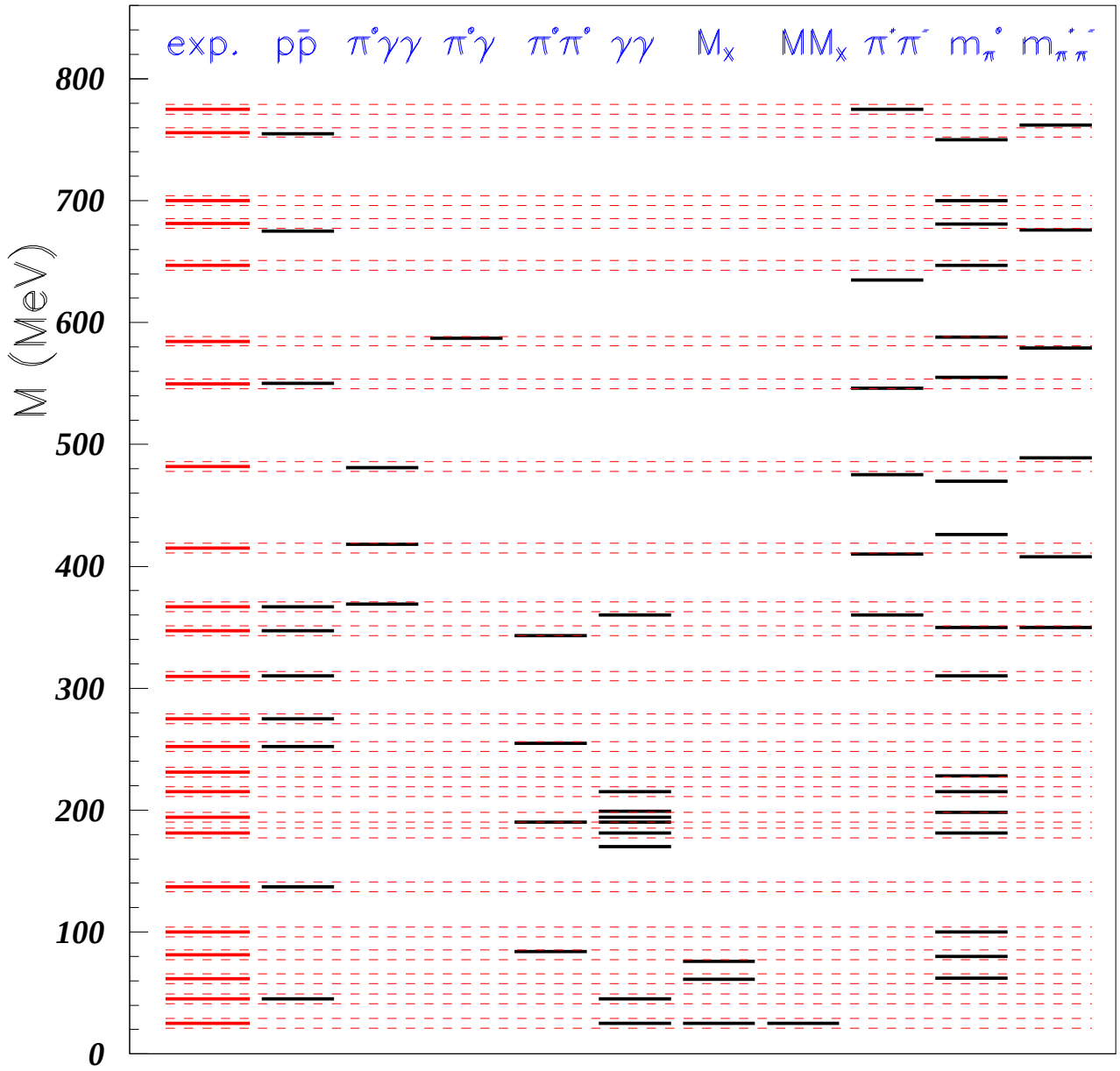
Collection of experimental exotic meson masses



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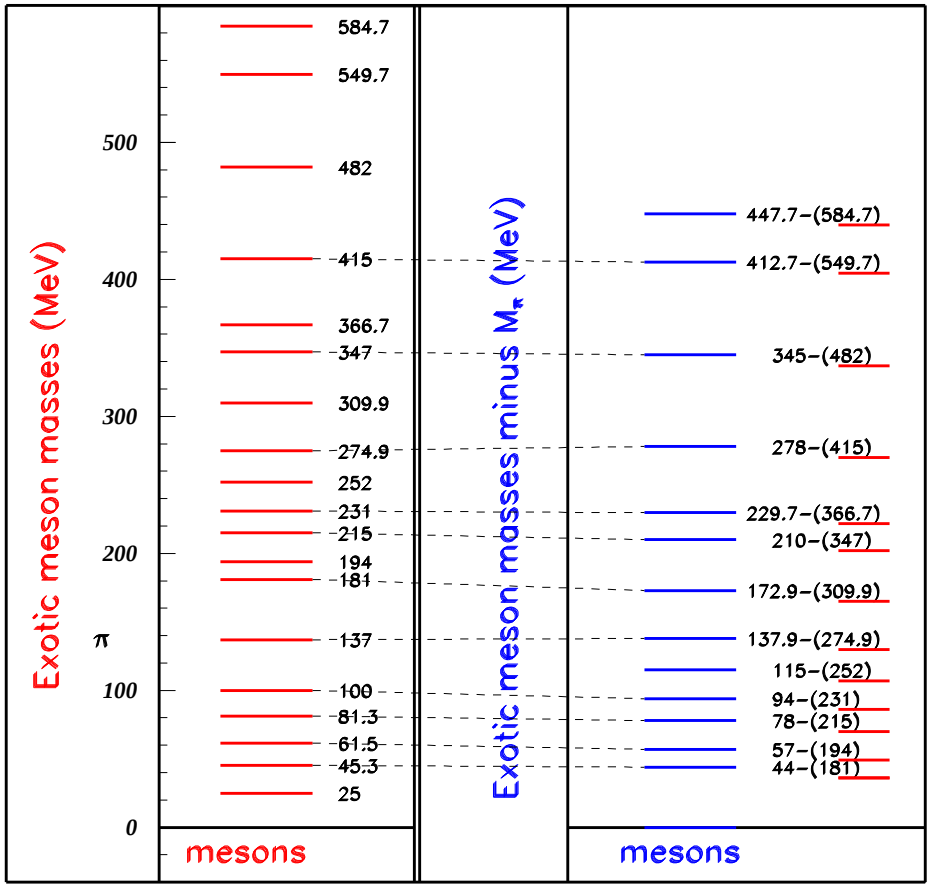
Molecular states, from low mass exotic mesonic structures and pion ?



- Above the pion mass the mass sequence is repeated.
- After subtraction of the pion mass impressive matching of the levels.

$$M_{high} \approx M_\pi + M_{low}$$

- Multi(quark-antiquark) balls (or clusters) with intermediate lifetimes.
- Molecular states ?

Significant coupling to other low mass stable hadrons

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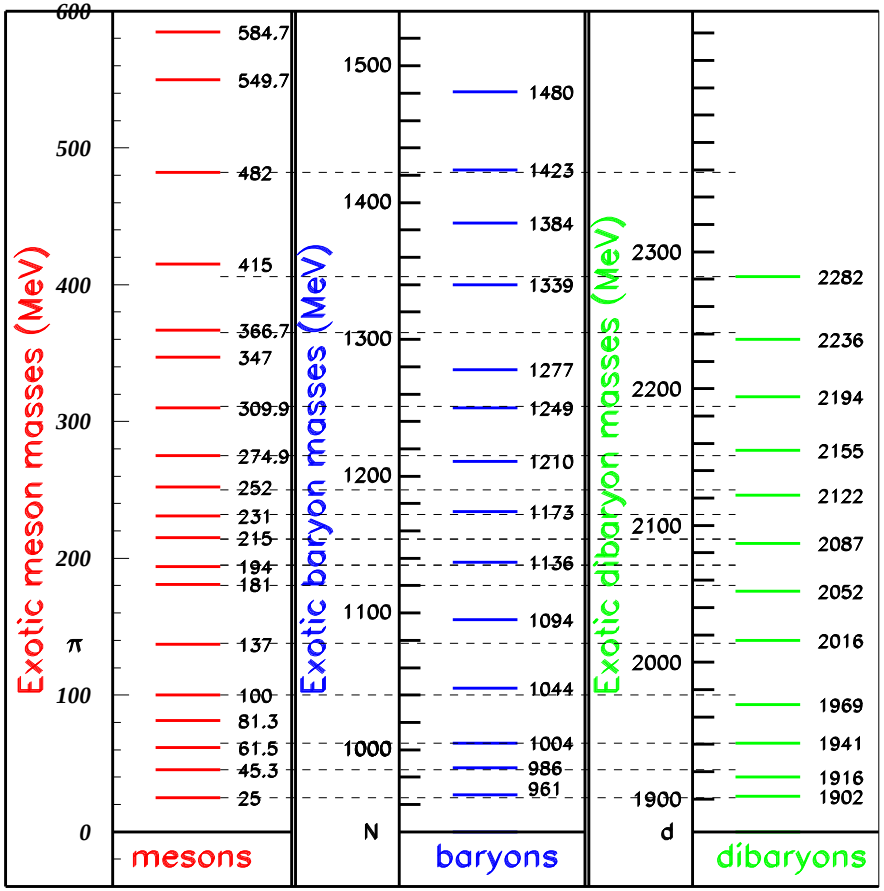
Relation between narrow exotic hadrons : mesons, baryons, and dibaryons

- *Many data from different labs, experiments...*
- *main results from SPES3 (Saturne)*



- mesons : Open Physics Journal (2014) $pp \to ppX^0$, M_X.
- baryons : EPJA **17**, 245 (2003) $pp \to p\pi^+X$, M_X, $M_{p\pi^+}$, M_{π^+X}.
- dibaryons : PRC **59**, 1878 (1999) $pp \to p\pi^+X$, M_{pX}.

Interpretation

Assumption : $q-\bar{q}$, $q^2-\bar{q}^2$, or $q^3-\bar{q}^3$ ... configurations :

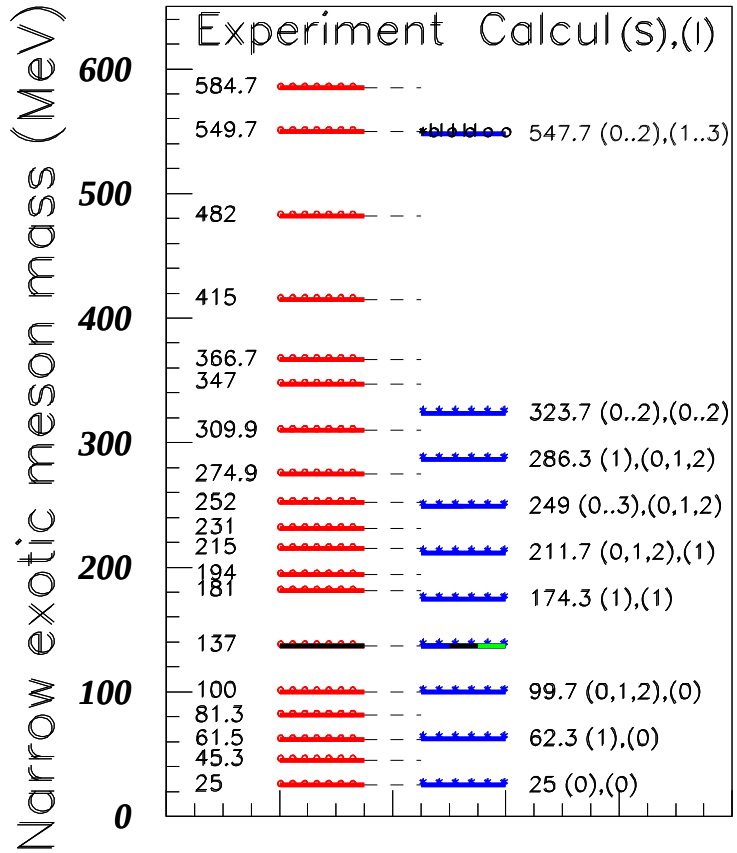
$$M = M_0 + M_1[i_1(i_1+1)+i_2(i_2+1)+(1/3)s_1(s_1+1)+(1/3)s_2(s_2+1)]$$

Parameters : M_0 and M_1,
isospin $i_{1,2}$, spin $s_{1,2}$

$q-\bar{q} \rightarrow \pi$ (M=137 MeV)
$s_1 = s_2 = i_1 = i_2 = 1/2$
$\rightarrow M = M_0 + 2M_1$

$q^2-\bar{q}^2 \rightarrow$ 25 MeV (lowest mass)
$s_1 = s_2 = i_1 = i_2 = 0 \rightarrow M = M_0$
hence $M_1 = 56$ MeV

Large degeneracy
9 masses within $q^2-\bar{q}^2$ assumption



One assumption(relation) and one adjusted parameter

Assumption : the simplest configuration is preferred, otherwise allowed spin and isospin will increase $\rightarrow$ Additional $q\bar{q}$ configurations with the different parity and same energy.

Interpretation

Assumption : $q-\bar{q}$, $q^2-\bar{q}^2$, added $q^3-\bar{q}^3$ configurations :

$$M = M_0 + M_1[i_1(i_1+1)+i_2(i_2+1)+(1/3)s_1(s_1+1)+(1/3)s_2(s_2+1)]$$

Parameters : M_0 and M_1,
isospin $i_{1,2}$, spin $s_{1,2}$

$q-\bar{q} \rightarrow \pi$ (M=137 MeV)
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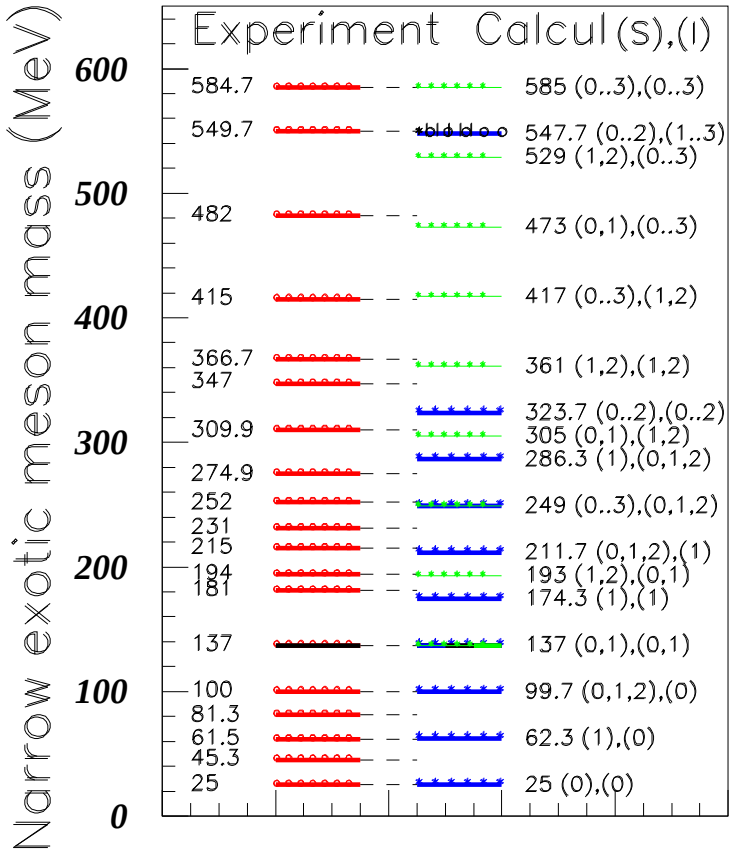

$q^3-\bar{q}^3$ clusters allow good fit up to M=585 MeV where
$i_1 = i_2 = s_1 = s_2 = 3/2$

One assumption(relation) and one adjusted parameter

Experimental and calculated exotic meson masses

u and d quarks, only

exp. mass [MeV]	quark cont.	s_1	s_2	i_1	i_2	calc [MeV]	$\lvert(\Delta M)\rvert/M$	J	I
137 (π)	$q-\bar{q}$	1/2	1/2	1/2	1/2	137	0	0,1	0,1
25	$q^2-\bar{q}^2$	0	0	0	0	25	0	0	0
45.3									
61.5	$q^2-\bar{q}^2$	1	0	0	0	62.3	$1.3\ 10^{-2}$	0	1
81.3									
100	$q^2-\bar{q}^2$	1	1	0	0	99.7	$3\ 10^{-3}$	0	0,1,2
137	$q^2-\bar{q}^2$	0	0	1	0	137	0	0	1
181	$q^2-\bar{q}^2$	1	0	1	0	174.3	$3.7\ 10^{-2}$	1	1
194	$q^3-\bar{q}^3$	1/2	3/2	1/2	1/2	193	$5.2\ 10^{-3}$	0,1	1,2
215	$q^2-\bar{q}^2$	1	1	1	0	211.7	$1.6\ 10^{-2}$	1	0,1,2
231									
252	$q^2-\bar{q}^2$	0	0	1	1	249	$1.2\ 10^{-2}$	0,1,2	0
252	$q^3-\bar{q}^3$	3/2	3/2	1/2	1/2	249	$1.2\ 10^{-2}$	0,1,2,3	0,1
274.9	$q^2-\bar{q}^2$	1	0	1	1	286.3	$4.2\ 10^{-2}$	0,1,2	1
309.9	$q^3-\bar{q}^3$	1/2	1/2	3/2	1/2	305	$1.6\ 10^{-2}$	1,2	0,1
347	$q^2-\bar{q}^2$	1	1	1	1	323.7	$6.7\ 10^{-2}$	0,1,2	0,1,2
366.7	$q^3-\bar{q}^3$	3/2	1/2	3/2	1/2	361	$1.6\ 10^{-2}$	1,2	1,2
482	$q^3-\bar{q}^3$	1/2	1/2	3/2	3/2	473	$1.9\ 10^{-2}$	0,1,2,3	0,1
549.7	$(q\bar{q})^2-(q\bar{q})$	1	1	2	1	547.7	$3.7\ 10^{-3}$	0,1,2	1,2,3
584.7	$q^3-\bar{q}^3$	3/2	3/2	3/2	3/2	585	$5.1\ 10^{-4}$	0,1,2,3	0,1,2,3

M = 45.3, 81.3 and 231 MeV : not reproduced.

M= 181, 274.9, and 347 MeV : not well reproduced

($\Delta M/M \geq 2 \cdot 10^{-2}$)

Partial summary

- Precise spectra (statistics, resolution, and binning) exhibit weakly excited narrow structures.
- Rather stable masses observed from different reactions, studied in different laboratories, with different detections and different physicists.
- Above limited to mesons, but similar observation for narrow weakly excited baryonic, or dibaryonic structures.
- Observations suggest new physics in low mass hadrons.
- A mass formula with two quark clusters, reproduce most of the observed masses with only one parameter $\rightarrow$ unique "explanation" up to now.
- Does the mass formula describe PDG meson masses ?

Unflavoured PDG meson masses

Meson	Mass [MeV]	$I^G(J^{PC})$	quark content	calc [MeV]	$\Delta M/M$
η	547.9	$0^+(0^{-+})$	$(q\bar{q})^2-(q\bar{q})$	600	$9.5\ 10^{-2}$
η	547.9	$0^+(0^{-+})$	$(S\bar{S})-(q\bar{q})$	500	$8.7\ 10^{-2}$
ρ	775.5	$1^+(1^{--})$	$(q\bar{q})q-(q\bar{q})\bar{q}$	750	$3.2\ 10^{-2}$
ρ	775.5	$1^+(1^{--})$	$(q\bar{q})-(q\bar{q})$	800	$3.2\ 10^{-2}$
ω	782.7	$0^-(1^{--})$	$(q\bar{q})-(q\bar{q})$	800	$2.2\ 10^{-2}$
η'	957.8	$0^+(0^{-+})$	$(q\bar{q})S-(q\bar{q})\bar{S}$	975	$1.8\ 10^{-2}$
η'	957.8	$0^+(0^{-+})$	$(q\bar{q})q-(q\bar{q})\bar{q}$	900	$6\ 10^{-2}$
a_0	980	$1^-(0^{++})$	$(q\bar{q})-(q\bar{q})^2$	1000	$2.0\ 10^{-2}$
f_0	990	$0^+(0^{++})$	$(q\bar{q})-(q\bar{q})^2$	1000	$1.0\ 10^{-2}$
Φ	1019.5	$0^-(1^{--})$	$(q\bar{S})-(S\bar{q})$	1025	$5.4\ 10^{-3}$
h_1	1170	$0^-(1^{+-})$	$(q\bar{q})^2-(q\bar{q})^2$	1200	$2.4\ 10^{-2}$
b_1	1229.5	$1^+(1^{+-})$	$(q\bar{q})^2-(q\bar{q})^2$	1200	$2.4\ 10^{-2}$
a_1	1230	$1^-(1^{++})$	$(q\bar{q})^3-(q\bar{q})^3$	1200	$2.4\ 10^{-2}$
f_2	1275.1	$0^+(2^{++})$	$(q\bar{q})-(q\bar{q})^3$	1300	$2.0\ 10^{-2}$
f_1	1282.1	$0^+(1^{++})$	$(q\bar{q})q-(q\bar{q})\bar{q}$	1300	$2.0\ 10^{-2}$
η	1294	$0^+(0^{-+})$	$(q\bar{q})S-(q\bar{q})\bar{S}$	1275	$1.5\ 10^{-2}$
η	1294	$0^+(0^{-+})$	$(q\bar{q})q\bar{S}-(q\bar{q})\bar{q}S$	1350	$4.3\ 10^{-2}$
π	1300	$1^-(0^{-+})$	$(q\bar{q})q-(q\bar{q})^2\bar{q}$	1300	0
a_2	1318.3	$1^-(2^{++})$	$(q\bar{q})-(q\bar{q})^3$	1300	$1.4\ 10^{-2}$
π_1	1354	$1^-(1^{-+})$	$(q\bar{q})^2q-(q\bar{q})\bar{q}$	1350	$3.0\ 10^{-3}$
η	1408.9	$0^+(0^{-+})$	$(q\bar{q})q\bar{S}-(q\bar{q})\bar{q}S$	1425	$1.1\ 10^{-2}$
ω	1425	$0^-(1^{--})$	$(q\bar{q})S-(q\bar{q})^2\bar{S}$	1425	0
f_1	1426.4	$0^+(1^{++})$	$(q\bar{q})S-(q\bar{q})^2\bar{S}$	1425	$1.0\ 10^{-3}$
a_0	1474	$1^-(0^{++})$	$(q\bar{q})q-(q\bar{q})\bar{q}$	1500	$1.8\ 10^{-2}$
ρ	1465	$1^+(1^{--})$	$(q\bar{q})q-(q\bar{q})\bar{q}$	1500	$2.4\ 10^{-2}$
η	1476	$0^+(0^{-+})$	$(q\bar{q})\bar{q}-(q\bar{q})q$	1500	$1.6\ 10^{-2}$
η	1476	$0^+(0^{-+})$	$(q\bar{q})-(q\bar{q})(S\bar{S})$	1500	$1.6\ 10^{-2}$

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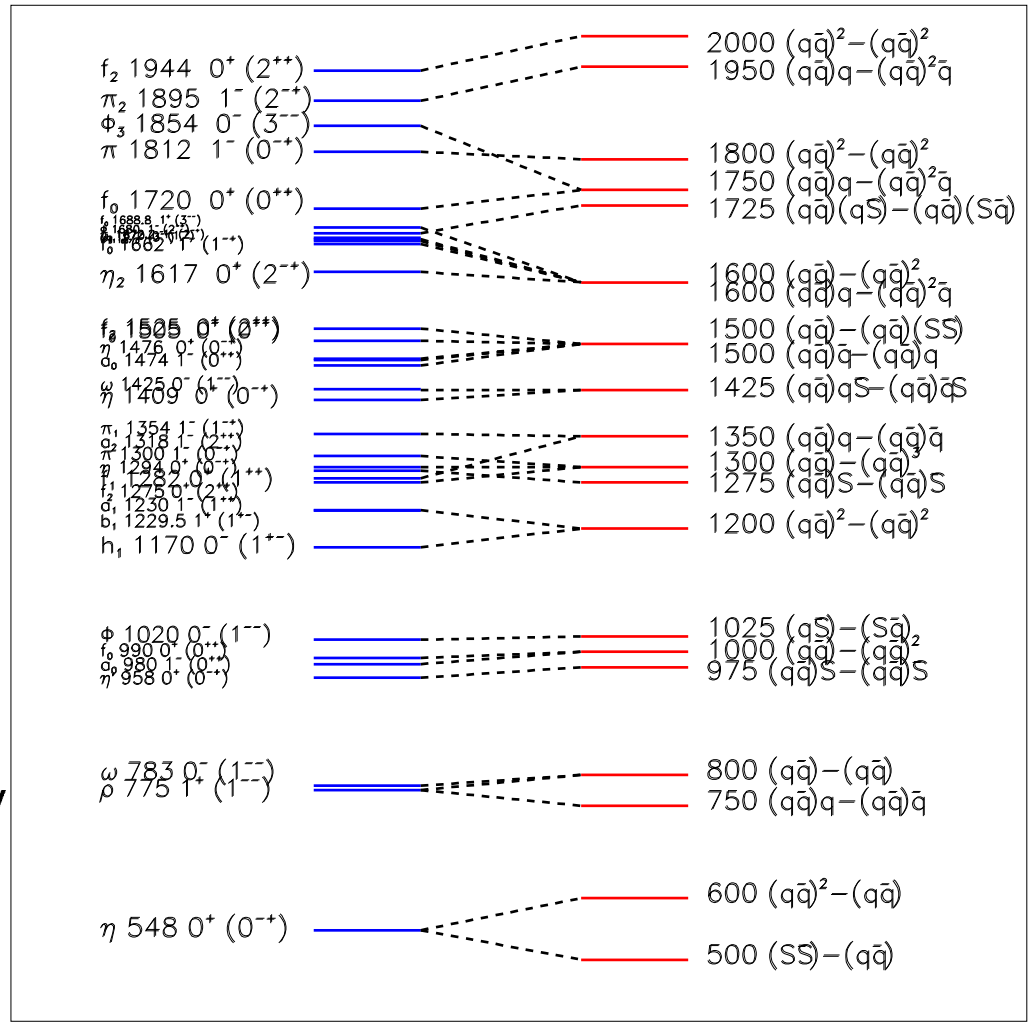
Unflavoured PDG meson masses

$$M = M_1[i_1(i_1+1)+i_2(i_2+1)+(1/3)s_1(s_1+1) +(1/3)s_2(s_2+1)+S_1(S_1+1)+S_2(S_2+1)]$$

Two quark clusters :
- q : u or d quark.
- S : strange quark.

Only one parameter
M_1=150 MeV
fitted on the ϕ mass

Relations :
- $\vec{i_1} + \vec{i_2} = \vec{I}$
- $\vec{s_1} + \vec{s_2} = \vec{s}$
- $\vec{s} + \vec{\ell} = \vec{J}$,
- J : particle spin.
- $P = (-1)^{\ell} \cdot N(a)$: parity
- $N(a)$ is the number of $\bar{q}$
- ℓ : orbital momentum between clusters



fulfills charge conjugaison, and G parity.

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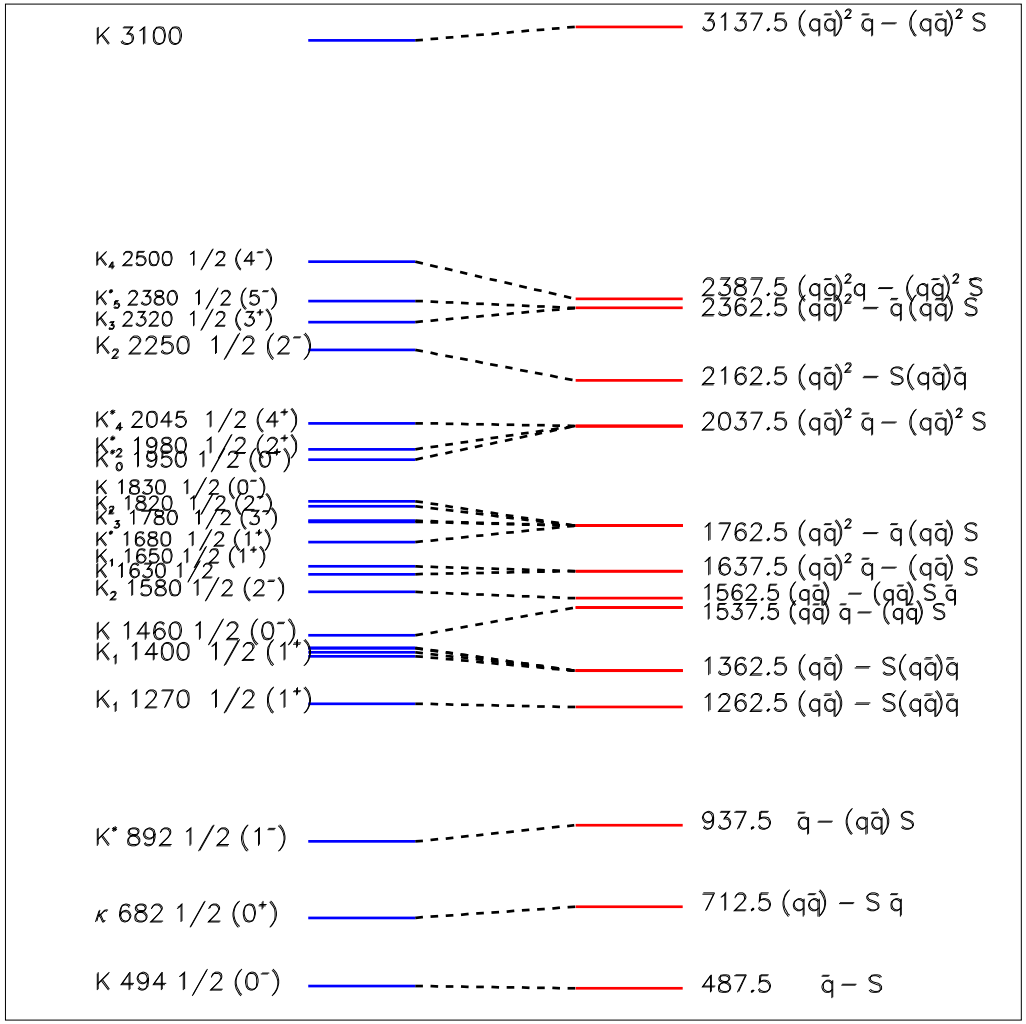
Strange PDG meson masses

$$M = M_1[i_1(i_1+1) + i_2(i_2+1) + (1/3)s_1(s_1+1) + (1/3)s_2(s_2+1) + S_1(S_1+1) + S_2(S_2+1)]$$

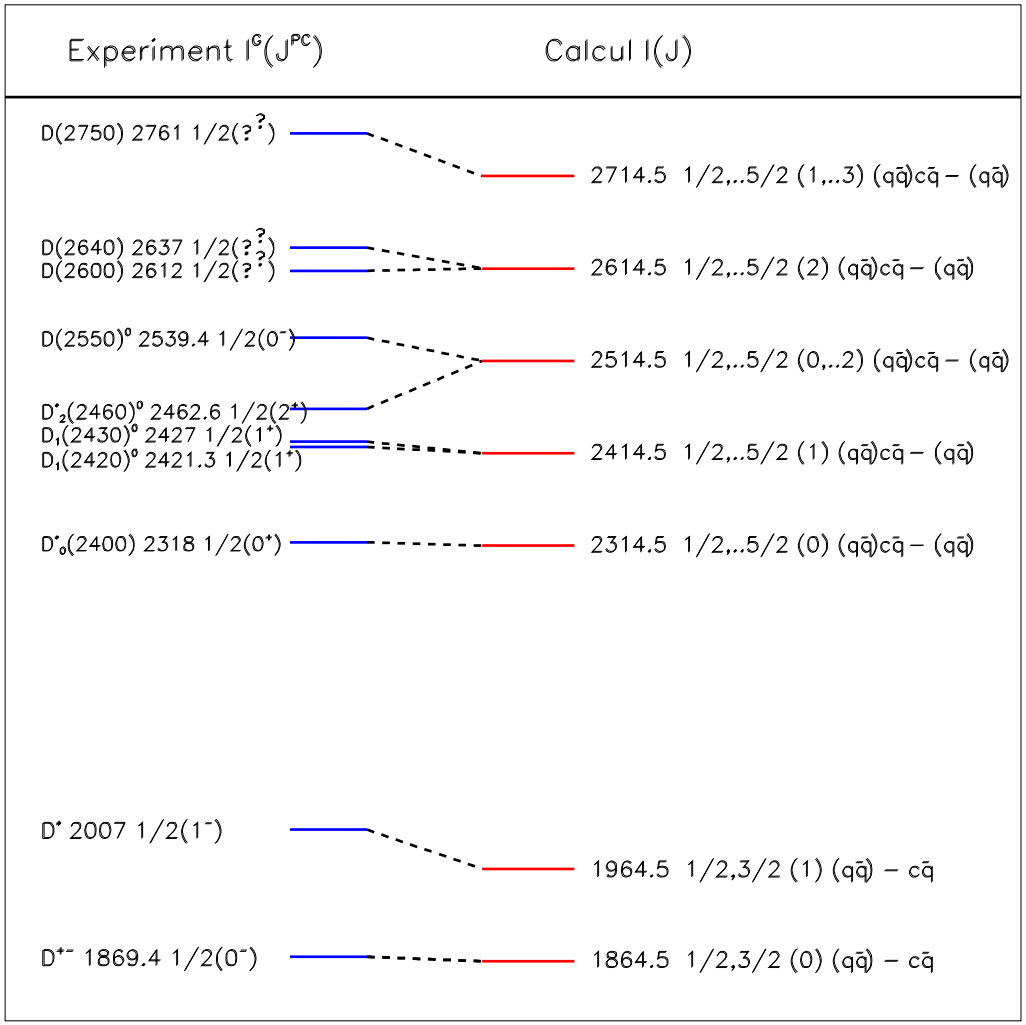
Two quark clusters :
- q : u or d quark.
- S : strange quark.

No new parameter
M_1=150 MeV
adjusted on the ϕ mass
($M = 1020$ MeV)

Relations :
- $\vec{i_1} + \vec{i_2} = \vec{I}$
- $\vec{s_1} + \vec{s_2} = \vec{s}$
- $\vec{s} + \vec{\ell} = \vec{J}$,
- J : particle spin.
- $P = (-1)^{\ell} \cdot N(a)$: parity
- $N(a)$ is the number of $\bar{q}$
- ℓ : orbital momentum between clusters



Experimental and calculated charmed meson masses



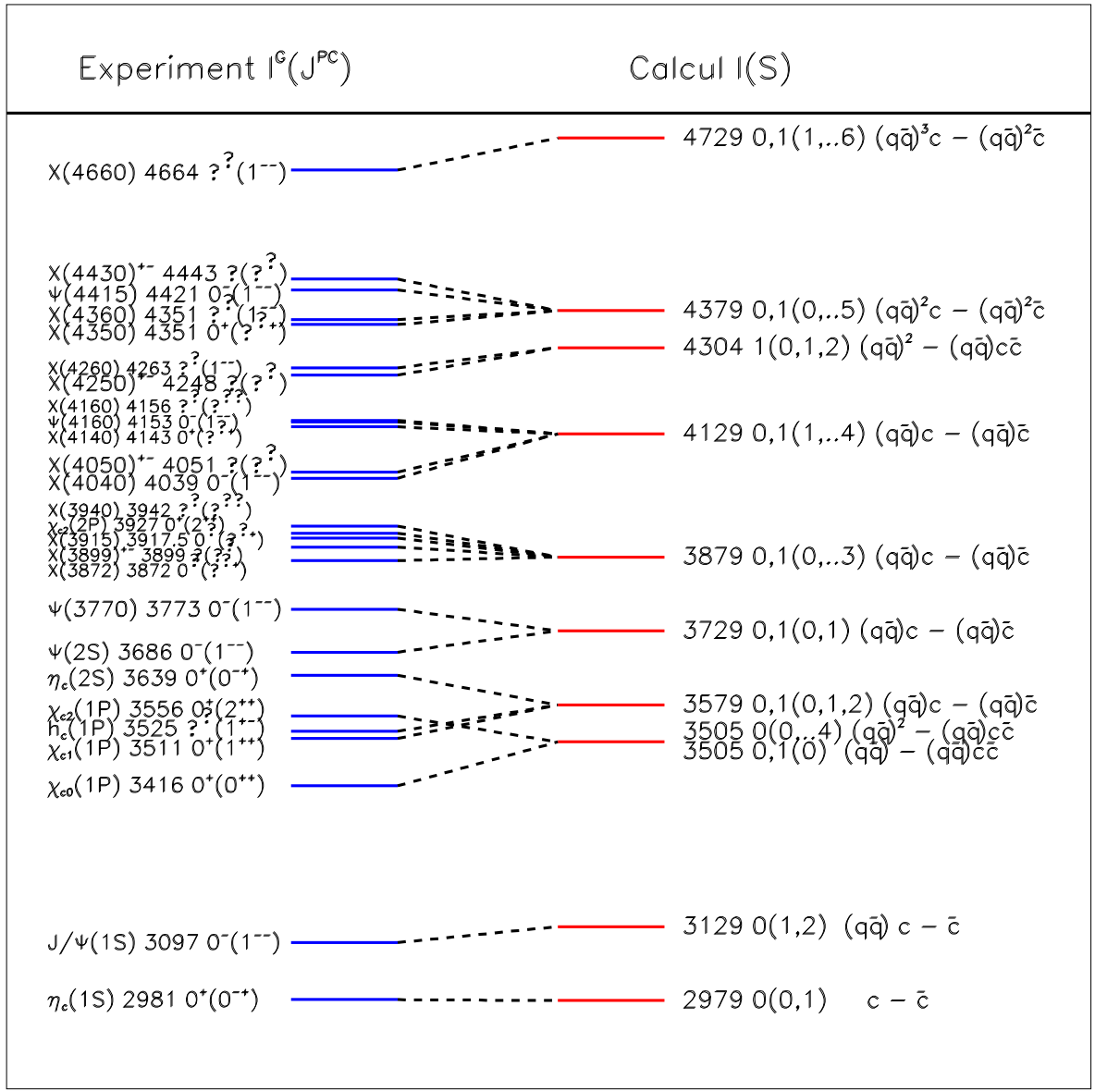
Experimental and calculated charmed meson masses

	mass	$I(J^P)$	quark content	i_1	i_2	s_1	s_2	calc.	$\|\Delta M\|/M$
$D^{\pm}$	1869.4	$1/2\ (0^-)$	$(q\bar{q}) - c\bar{q}$	1	1/2	0	0	1864.5	$2.6\ 10^{-3}$
$D^{\star}$	2007	$1/2\ (1^-)$	$(q\bar{q}) - c\bar{q}$	1	1/2	0	1	1964.5	$2.1\ 10^{-2}$
$D_0^{\star}(2400)$	2318	$1/2\ (0^+)$	$(q\bar{q})c\bar{q} - (q\bar{q})$	3/2	1	0	0	2314.5	$1.6\ 10^{-3}$
$D_1(2420)^0$	2421.3	$1/2\ (1^+)$	$(q\bar{q})c\bar{q} - (q\bar{q})$	3/2	1	1	0	2414.5	$2.8\ 10^{-3}$
$D_1(2430)^0$	2427	$1/2\ (1^+)$	$(q\bar{q})c\bar{q} - (q\bar{q})$	3/2	1	1	0	2414.5	$5.2\ 10^{-3}$
$D_2^{\star}(2460)^0$	2462.6	$1/2\ (2^+)$	$(q\bar{q})c\bar{q} - (q\bar{q})$	3/2	1	1	1	2514.5	$2.1\ 10^{-2}$
$D(2550)^0$	2539.4	$1/2\ (0^-)$	$(q\bar{q})c\bar{q} - (q\bar{q})$	3/2	1	1	1	2514.5	$9.8\ 10^{-3}$
$D(2600)$	2612	$1/2\ (?^?)$	$(q\bar{q})c\bar{q} - (q\bar{q})$	3/2	1	2	0	2614.5	$9.6\ 10^{-4}$
$D(2640)$	2637	$1/2\ (?^?)$	$(q\bar{q})c\bar{q} - (q\bar{q})$	3/2	1	2	0	2614.5	$8.5\ 10^{-3}$
$D(2750)$	2761	$1/2\ (?^?)$	$(q\bar{q})c\bar{q} - (q\bar{q})$	3/2	1	2	1	2714.5	$1.7\ 10^{-2}$

B. Tatischeff and Egle Tomasi-Gustafsson*

Experimental and calculated charmonium masses

$M_C = 726$ MeV

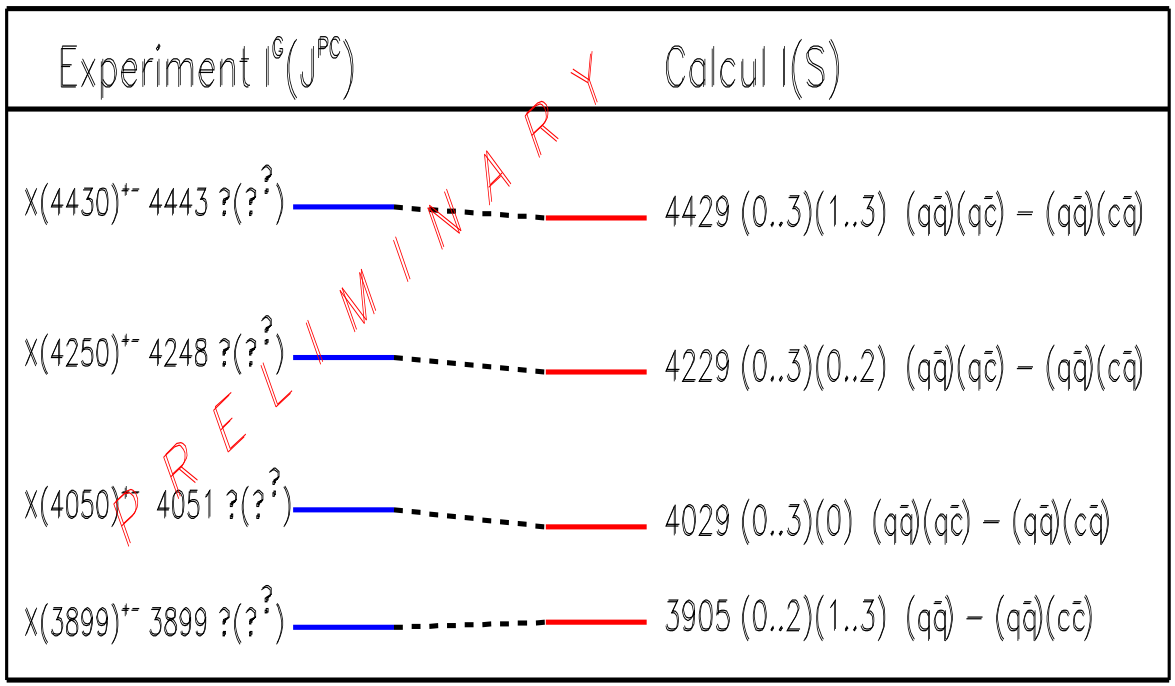


B. Tatischeff and Egle Tomasi-Gustafsson*

Experimental and calculated charmonium I=1 masses

$M_C = 726$ MeV $\qquad$ $M_1 = 150$ MeV

mass	$I(J^P)$	quark content	i_1	i_2	s_1	s_2	c_1	c_2	calc.	$\lvert\Delta M\rvert/M$
3899	$?(?^?)$	$(q\bar{q})(q\bar{c})$-$(q\bar{q})(c\bar{q})$	1/2	3/2	0	2	1	1	3879	$5.1\ 10^{-3}$
4051	$?(?^?)$	$(q\bar{q})(q\bar{c})$-$(q\bar{q})(c\bar{q})$	3/2	3/2	0	0	1	1	4029	$5.4\ 10^{-3}$
4248	$?(?^?)$	$(q\bar{q})(q\bar{c})$-$(q\bar{q})(c\bar{q})$	3/2	3/2	1	1	1	1	4229	$4.5\ 10^{-3}$
4443	$?(?^?)$	$(q\bar{q})(q\bar{c})$-$(q\bar{q})(c\bar{q})$	3/2	3/2	1	2	1	1	4429	$3.2\ 10^{-3}$



Summary

- Precise spectra (statistics, resolution, and binning) exhibit weakly excited narrow structures.
- Structures are observed from different reactions, studied in different laboratories, with different detections and different physicists.
- Similar observation for narrow weakly excited baryonic, or dibaryonic structures.
- Observations suggest new physics in low mass hadrons.
- A mass formula with two quark clusters, reproduce most of the observed masses with only one parameter $\rightarrow$ unique "explanation" up to now.
- Low mass(multiquark) clusters are significantly coupled to stable hadrons (nucleons $\rightarrow$ exotic baryons or deuterons $\rightarrow$ exotic dibaryons).
- The experimental masses of exotic narrow meson are evidently less precise than the PDG masses. Future precise, high statistics experiments should improve their determination.