HEAVY IONS AND EXOTIC RESONANCES

AD Polosa

2000: CERN ANNOUNCES THE DISCOVERY OF A NEW STATE OF MATTER

CERN Press Release

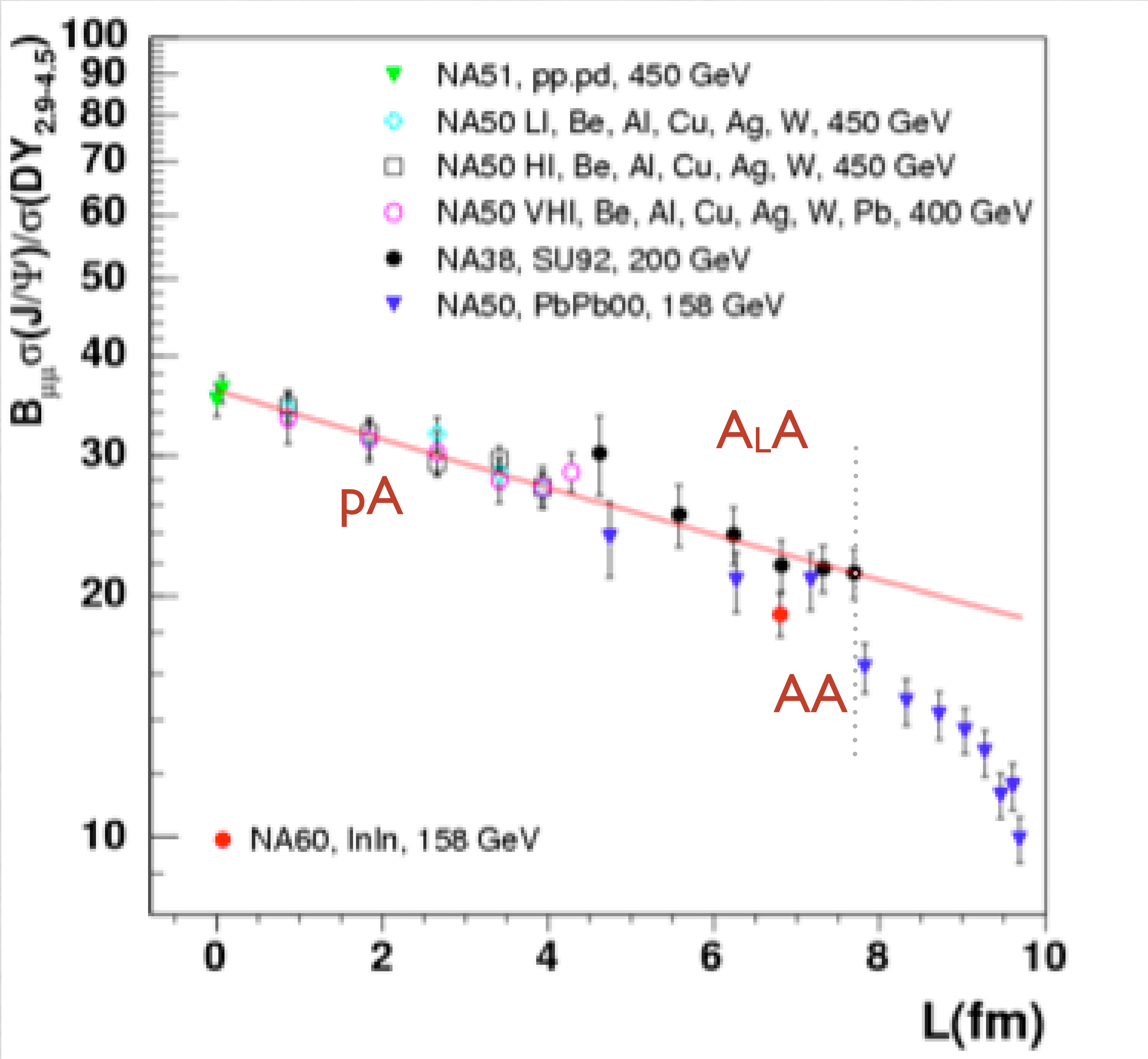
The CERN NA50 Experiment found

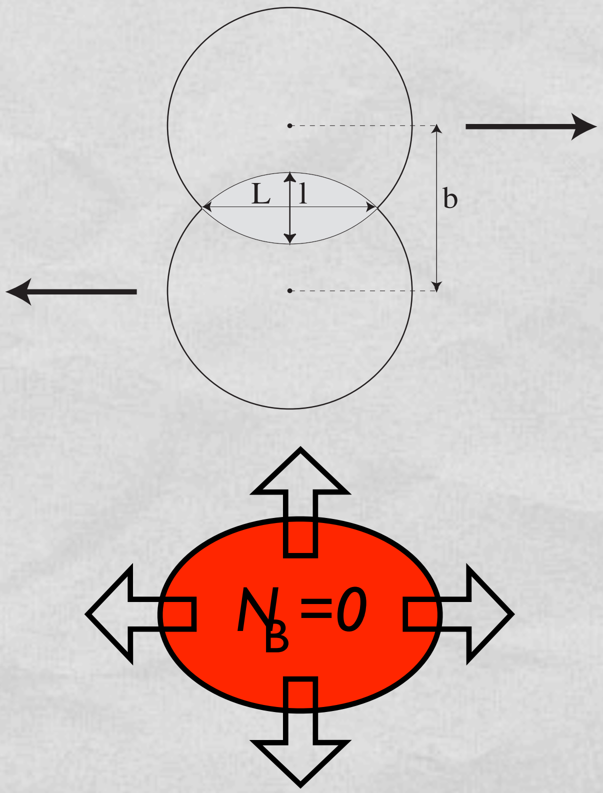
Evidence for deconfinement of quarks and gluons
from the J/psi suppression pattern
measured in Pb-Pb collisions at the CERN-SPS

Introduction to the anomalous J/psi suppression (PS file)

Physics Letters B 477 (2000) 28;
CERN-EP-2000-013

DATA FROM THE SPS ON PA & AA



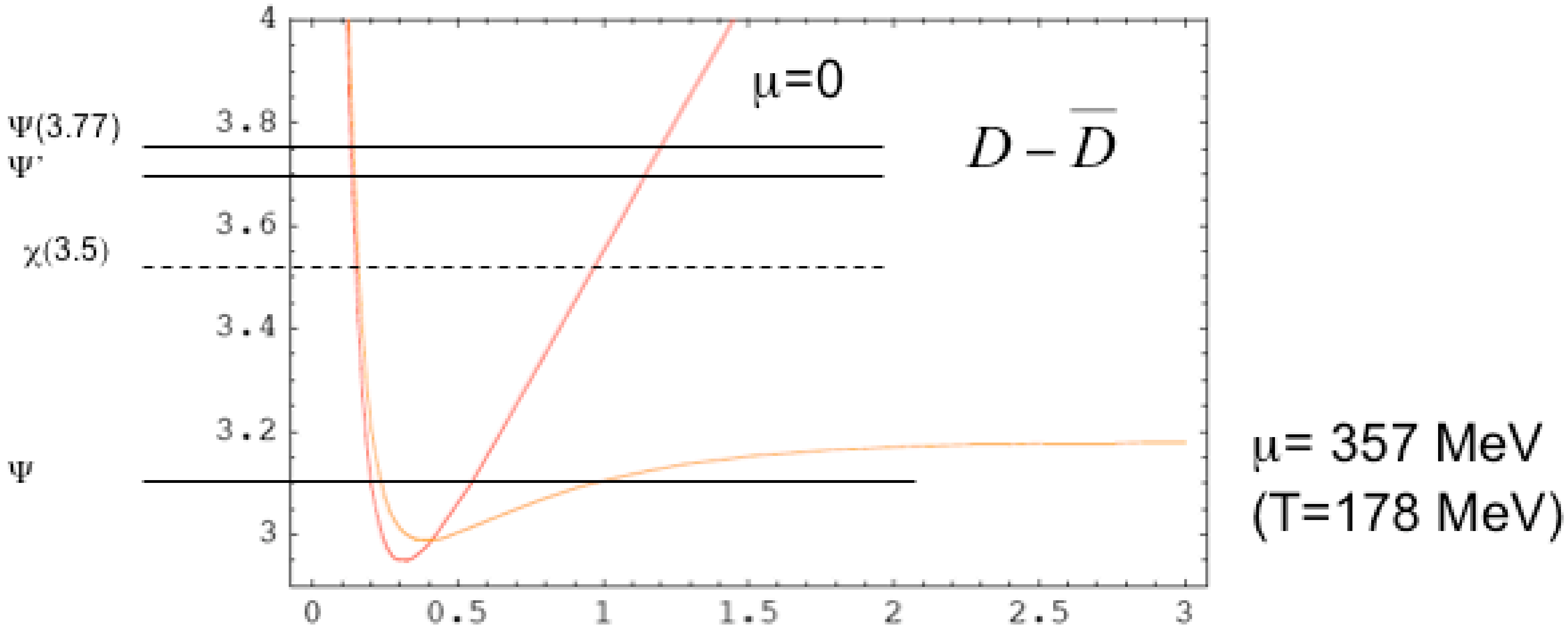


Standard QGP interpretation

$$V_{eff} = 2m_c + \frac{1}{m_c r^2} + V(r)$$

$$V(r) = \frac{\sigma}{\mu}(1 - e^{-\mu r}) - \frac{\alpha_c}{r} e^{-\mu r}$$

$2m_c$=2.64 GeV
σ = 0.192GeV^2
α_c=0.471



Ψ(1S), M= 3097 MeV
Ψ(2S), M= 3686 MeV
Above threshold:
Ψ(3.77), M= 3770.0 ± 2.4 MeV
Y(4.04), M= 4040 ± 10 MeV

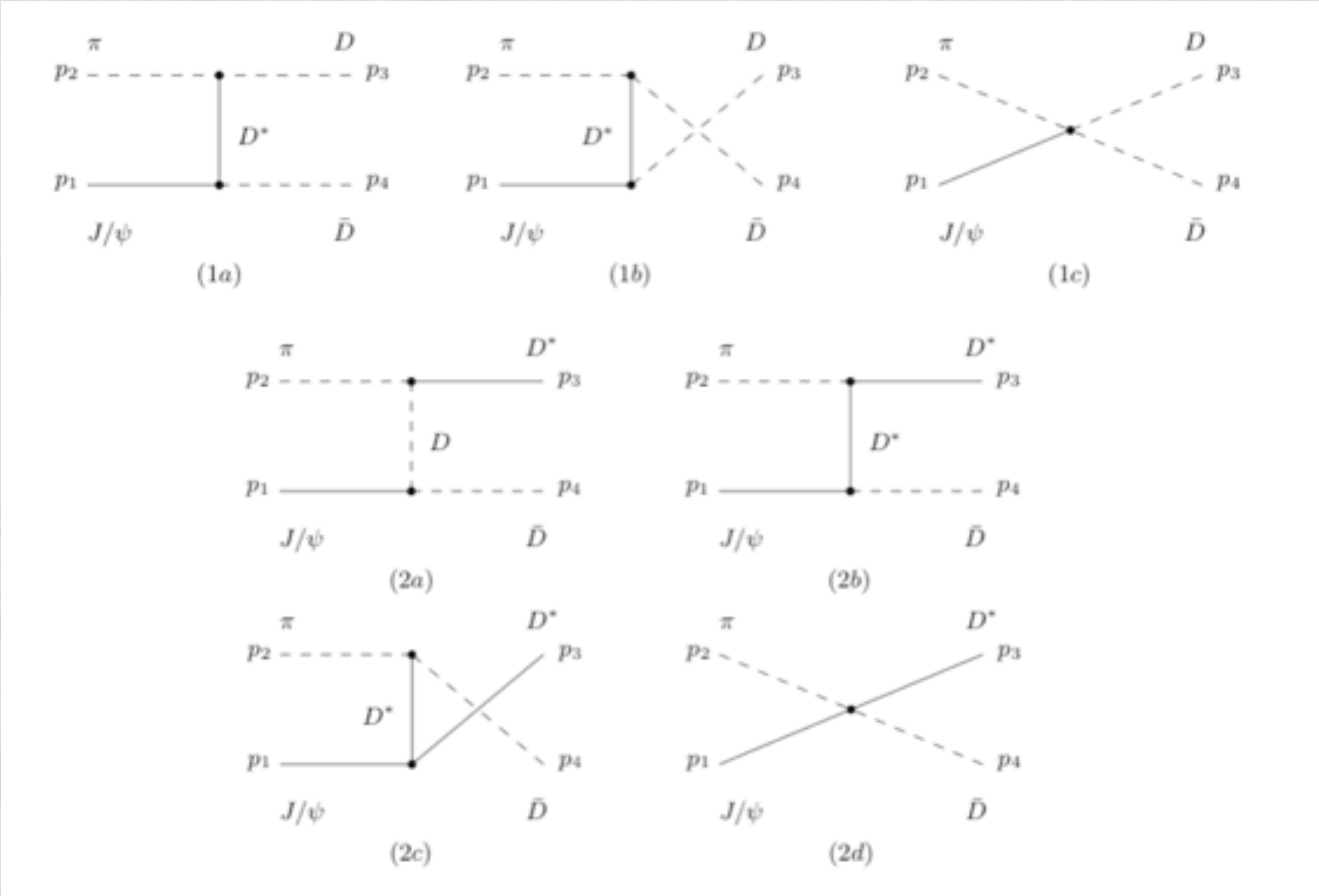
χ_{c0}(1P), M= 3415 MeV
χ_{c1}(1P), M= 3510 MeV
χ_{c2}(1P), M= 3556 MeV

Slide by Luciano, 2004

WHAT IS THE EFFECT OF AN HOT RESONANCE GAS PRODUCED IN THE COLLISION? (2003)

Discussions with Fulvio Piccinini

$$A(x) = N exp\left[-\frac{x}{\lambda_\pi(T)}\right]$$



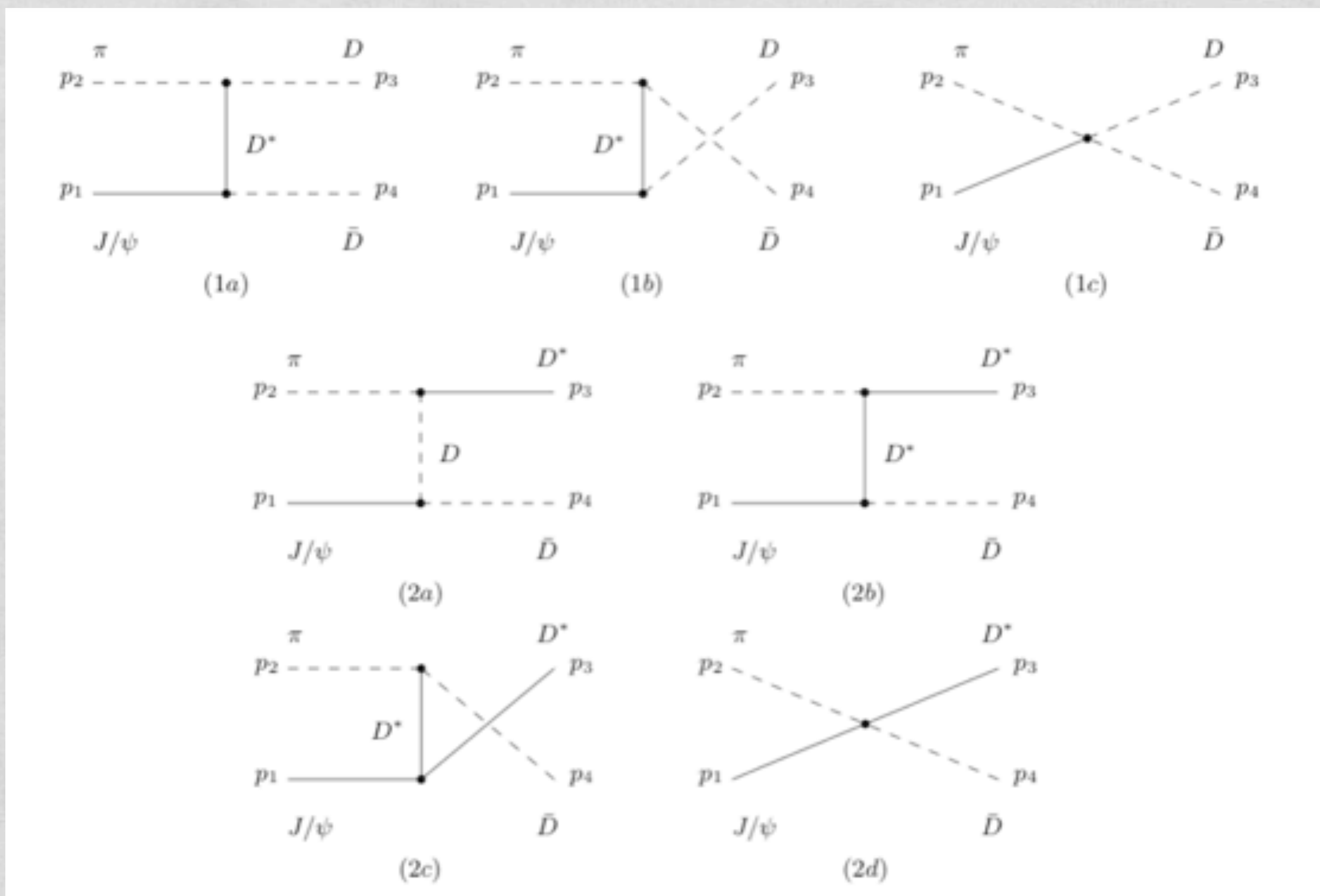
$$\lambda_\pi^{-1} = \langle \rho_\pi \sigma_{\pi J/\psi \to D^{(*)} D^{(*)}} \rangle_T = \frac{3}{2\pi^2} \int_{E_\pi^{thr.}}^{\infty} dE_\pi \frac{E_\pi^2 \sigma(E_\pi)}{e^{E_\pi/T} - 1}$$

WHAT IS THE EFFECT OF AN HOT RESONANCE GAS PRODUCED IN THE COLLISION? (2003)

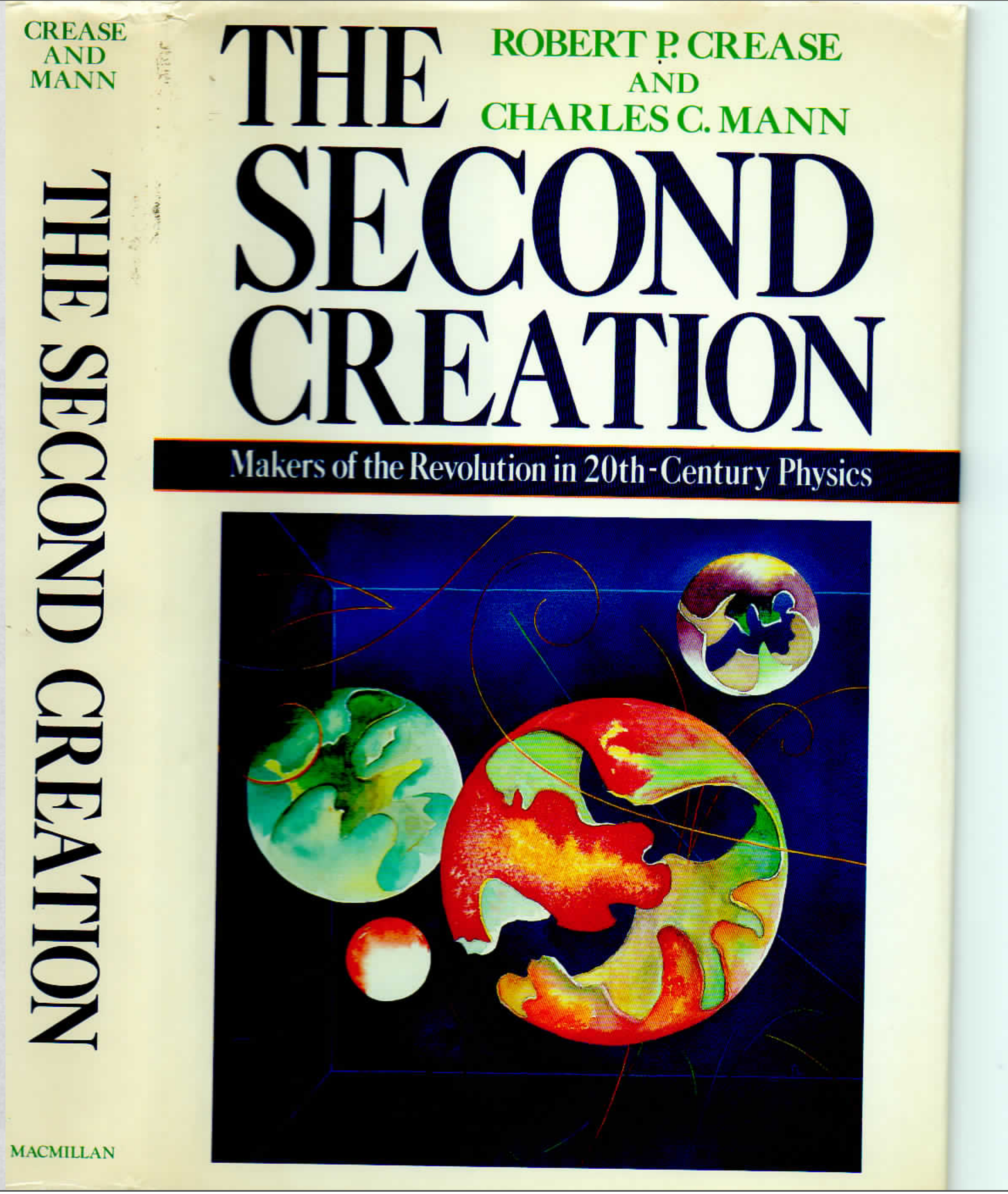
Discussions with Fulvio Piccinini

Veronica Riquer Ramirez joins the group and, unexpectedly, Luciano Maiani!

$$A(x) = N exp\left[-\frac{x}{\lambda_\pi(T)}\right]$$



$$\lambda_\pi^{-1} = \langle \rho_\pi \sigma_{\pi J/\psi \to D^{(*)} D^{(*)}} \rangle_T = \frac{3}{2\pi^2} \int_{E_\pi^{thr.}}^{\infty} dE_\pi \frac{E_\pi^2 \sigma(E_\pi)}{e^{E_\pi/T} - 1}$$


CREASE
AND
MANN
THE SECOND CREATION
MACMILLAN
THE
SECOND
CREATION
ROBERT P. CREASE
AND
CHARLES C. MANN
Makers of the Revolution in 20th-Century Physics

that have? You would produce parity-violating strong interactions, strangeness-violating strong interactions, which don't exist." They discovered that if they put in a clever symmetry-breaking mechanism, they could sweep the parity violation under the rug. This also got rid of the effects of the leading divergences.[5] "We were left with the next-to-leading divergences. They are equally bad, but you sort of say, 'Well, it's one power less, who cares?' " But even that didn't work: The next-to-leading divergences, although much smaller, made rare processes occur frequently. "So you had to get rid of those, too, hoping that somehow this would get inside, let you see the right thing." The whole procedure was intellectually untidy, mathematically unrigorous, but physics at the edge is frequently that way.

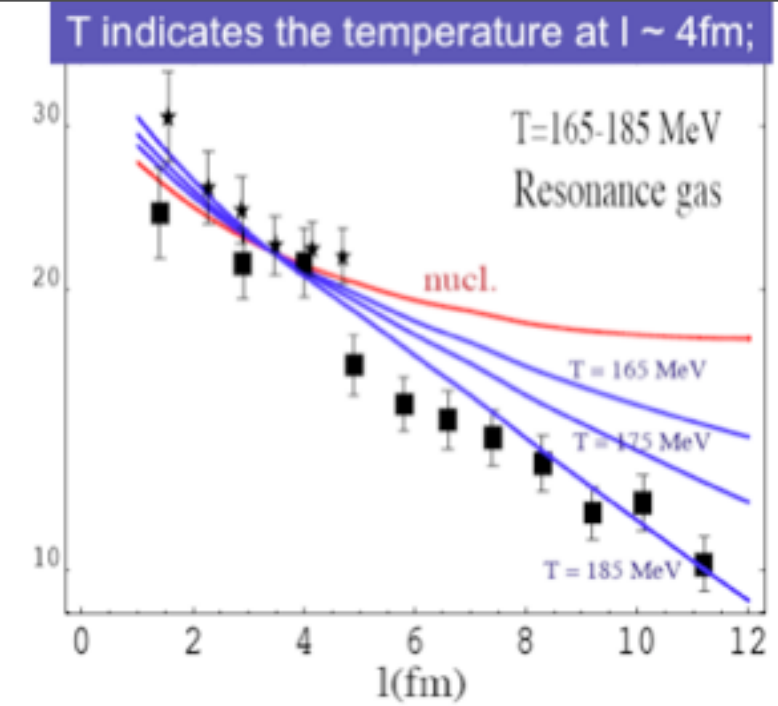
Glashow was visiting CERN, and Iliopoulos showed the half-complete work to him. Glashow, too, was pushing around the infinities in the weak interaction, working by brute force, trying to squeeze them into the edges where they wouldn't show. The two men decided to collaborate when Iliopoulos came to Harvard, and agreed that they could use the criterion of renormalizability to try to figure out a real theory. At the beginning of November, they were joined by Luciano Maiani, a young Italian field theorist. The three men's interests meshed immediately: All were working with the same level of ignorance on similar phenomena. Maiani brought some suggestions from Europe; Glashow and Iliopoulos rejected his ideas with the bluntness customary among physicists. Within two months, they had come up with a pivotal piece of the standard model.

The atmosphere around the University of Rome has the stillness of shell shock; the days when tear gas and terrorism accompanied students to class are not long gone, and the gateway to the school on Piazzale Aldo Moro is flanked by sullen *carabinieri*. Five years before, tanks were a feature of campus life. The university is large, desolate, creakingly underfinanced; the heavy neoclassic buildings of the science wings are sprayed with political graffiti and surrounded by indifferently tended islands of grass. Luciano Maiani's office is on the second floor, in the middle of a twist of dusty corridors. A graduate student guided us through, silent as Charon, turning imperturbably this way and that in the dim light.

Maiani was waiting for us, a cigarette burning in a sixteen-millimeter film canister that served as an ashtray. He has a large head, expressive dark blue eyes, and black hair that is swept back from a high forehead sticking out to the side like the cartoon image of an orchestra conductor. His voice is deep, penetrating, an unmistakable peninsular bass. "Want one of these?" he asked, pushing the cigarette box across the desk. They were MS, the state-owned brand. "MS, *morte sicura*," he said. "They are disgusting."

Maiani's family is from San Marino, the minute city-state in northern

Maiani, Piccinini, Polosa, Riquer,
Nucl Phys A741, 273 (2004); Nucl Phys A748, 209 (2005);



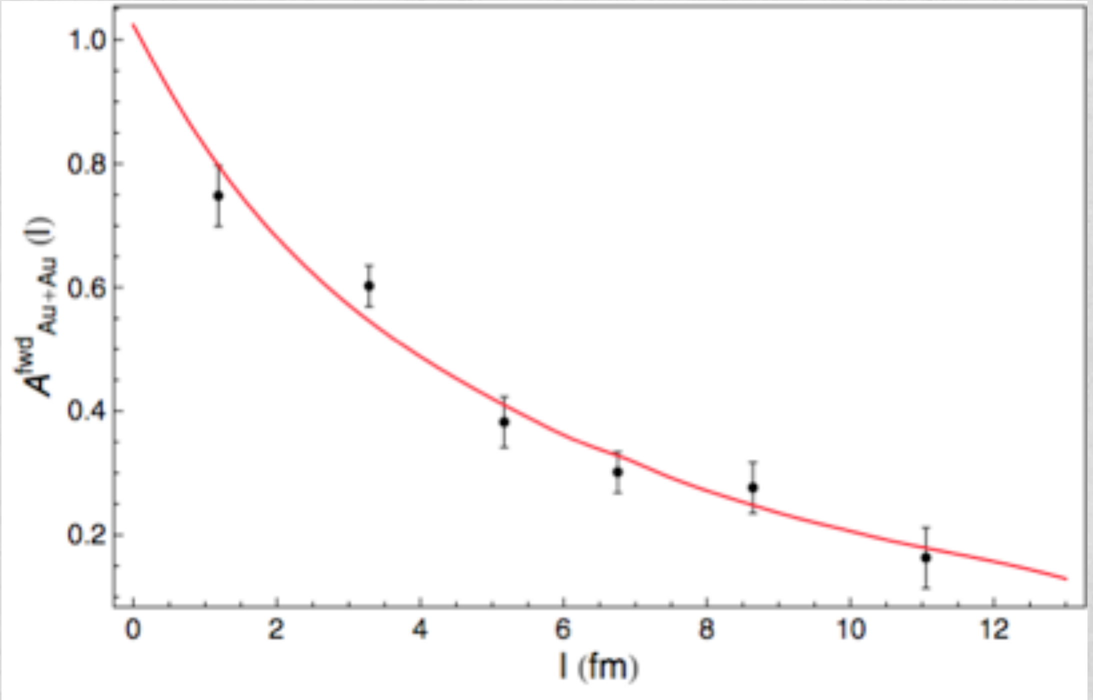
J/Ψ as a probe of QGP: conclusions

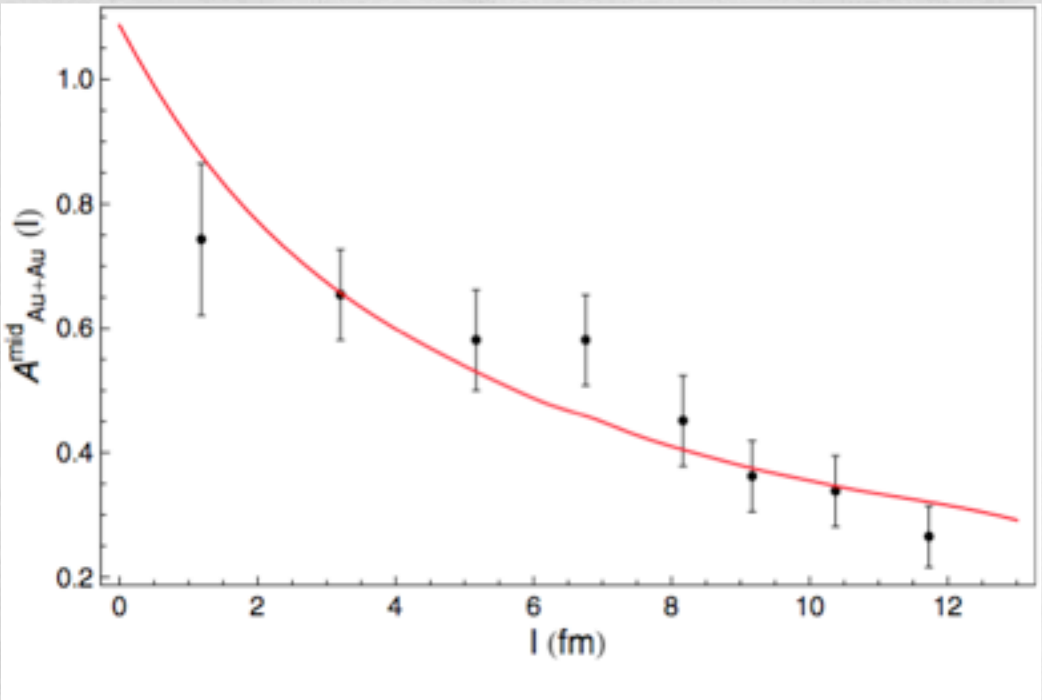
- When the idea was proposed, it was believed that J/Ψ would suffer very little absorption from nuclear matter and from the "comoving particles" (σ<1 mb) hence very little background to the QGP signal;
- Nuclear absorption measured from p-A cross sections (but uncertainties still remain!) ~ 4-5 mb, attenuation lenght ~ 0.07 fm, signal:noise ~ 1;
- Absorption by comoving particles: many calculations, results mostly in the few mb range;
- We have made a complete analysis of Ps and V meson cross-sections, in a reliable model (CQM) tested in other processes, and applied the results to a hadron gas made of Ps and V mesons;
- Effects of comovers (i) non negligible and (ii) strongly T dependent;
- If we allow T in excess of 200 MeV we can fit NA50 results in this hadron gas, no QGP, only marginally;
- If there is a limiting temperature to the hadronic phase around 170 MeV, comovers cannot explain the drop in J/Ψ production seen at large centralities by NA50;
- The picture that QGP sets in at centrality ~ 5 fm is consistent with known T and energy density ranges;
- The drop in J/Ψ would be due first to χ_c and, later, to Ψ' melting;

Slide by Luciano, 2004

AT RHIC (USING HAGEDORN GAS MODEL)

Brazzi, Grinstein, Piccinini, Polosa, Sabelli, Phys. Rev D84, 014003 (2011)



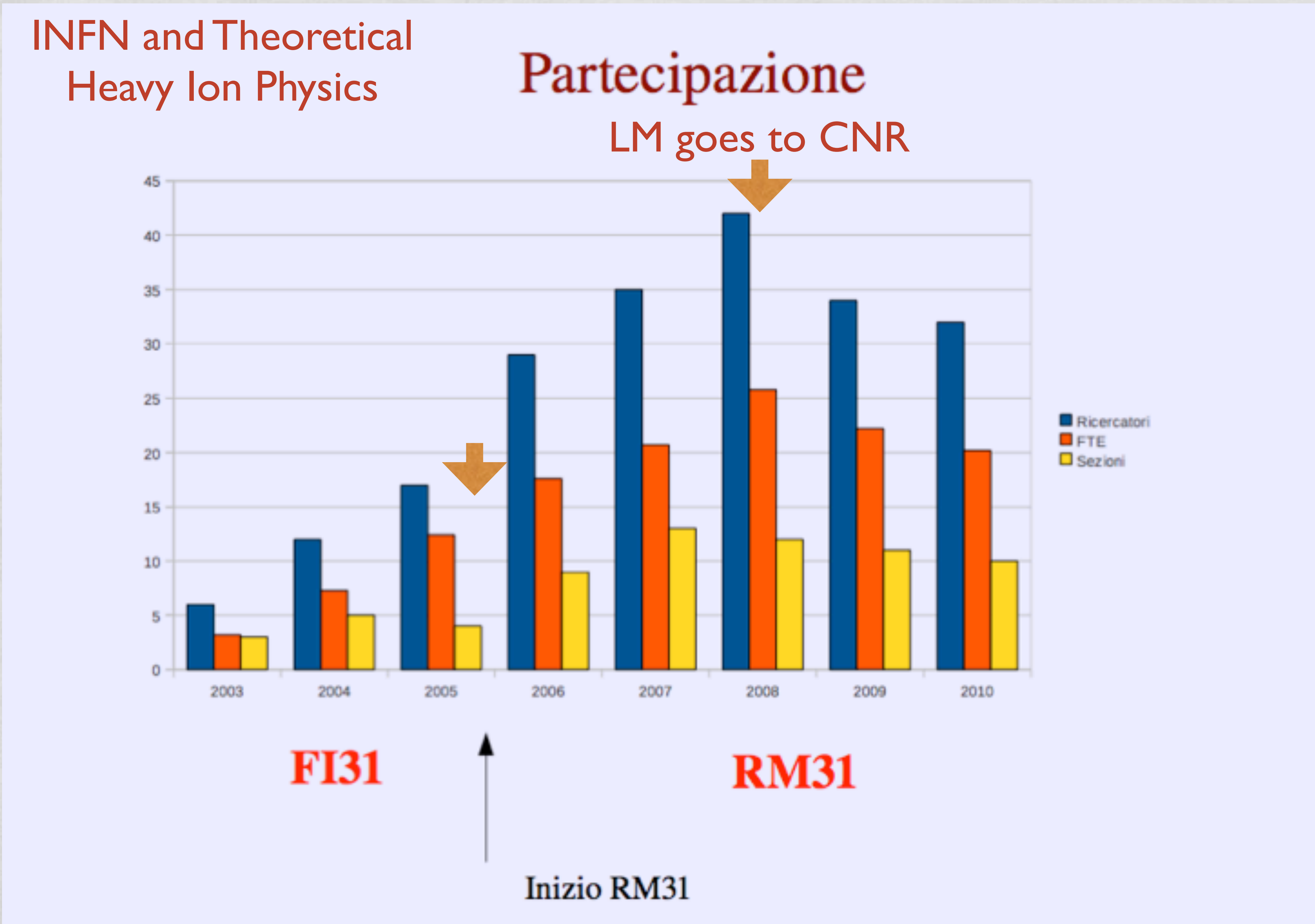


1.2<y<2.2

|y|<0.35

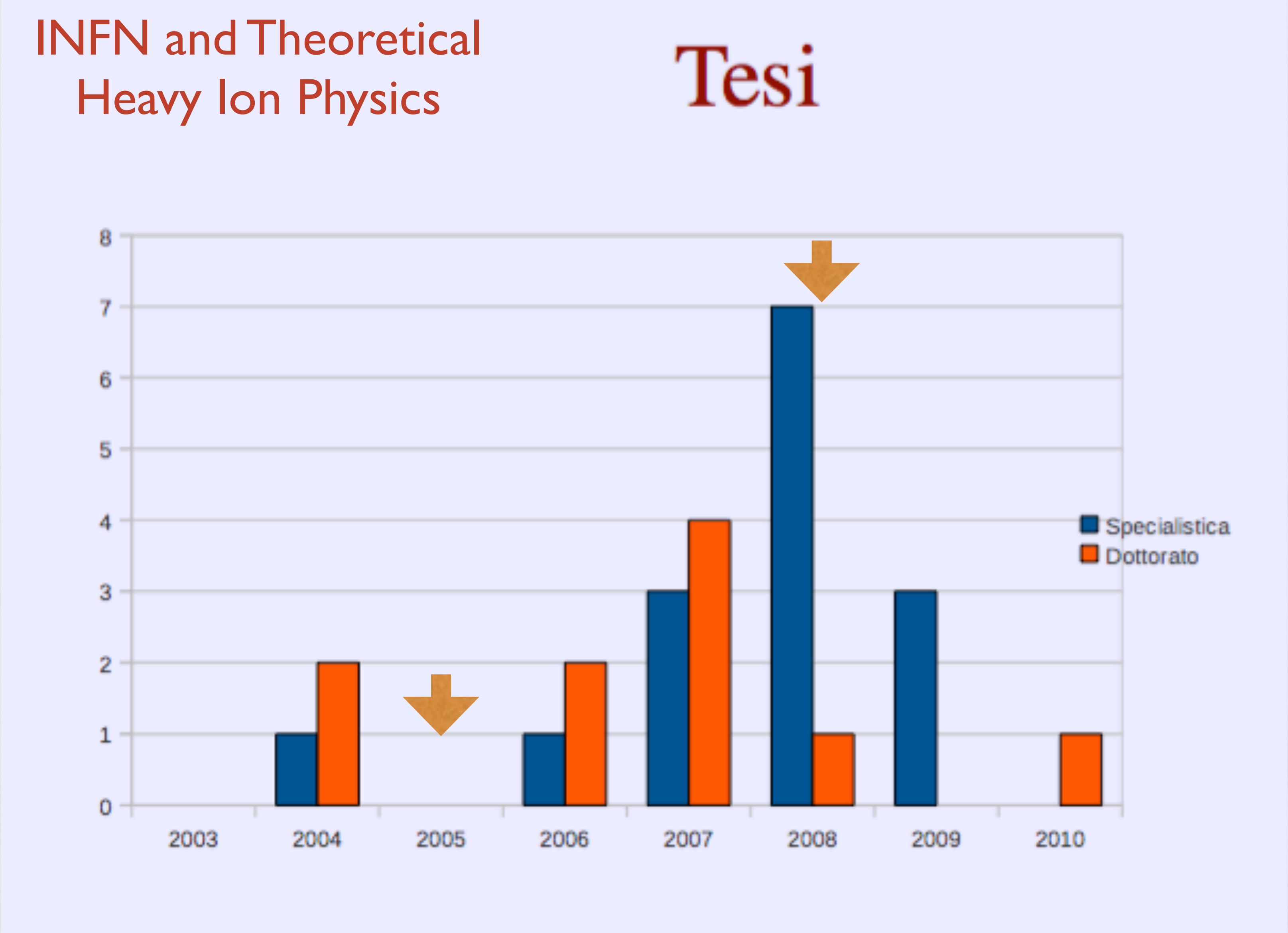
At the Hagedorn temperature T_H = 177 MeV

‘THE MAIANI EFFECT’



Slide by F Becattini, 2010

'THE MAIANI EFFECT'

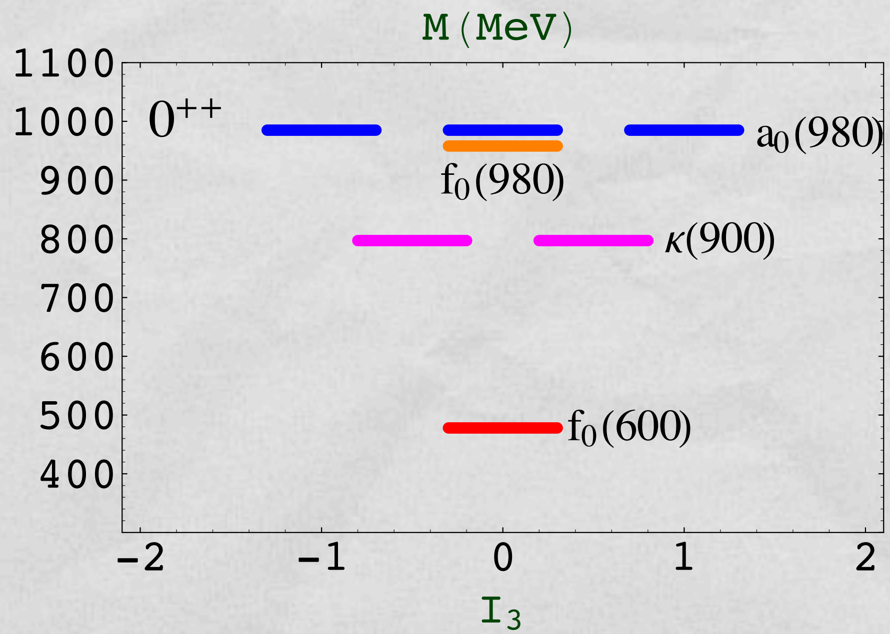


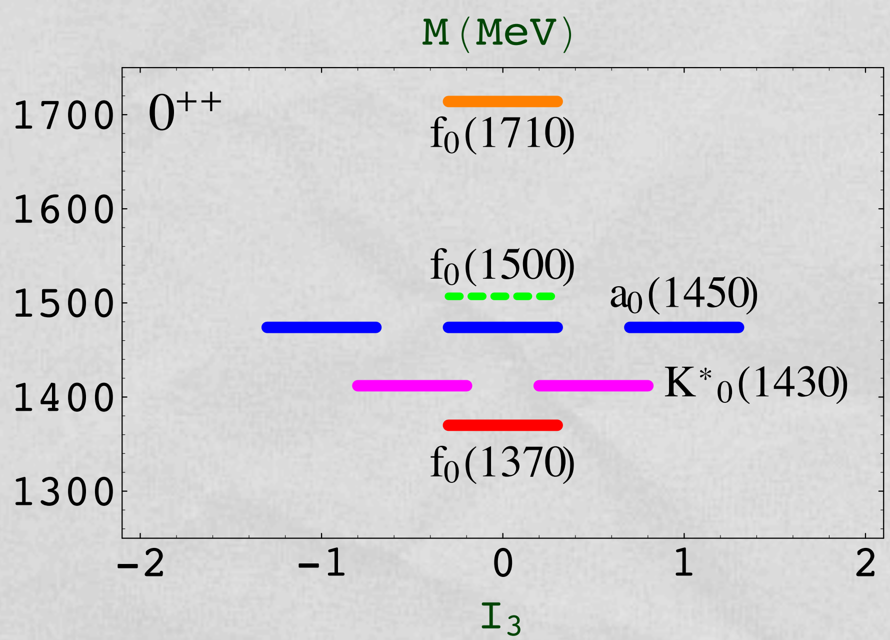
Slide by F Becattini, 2010

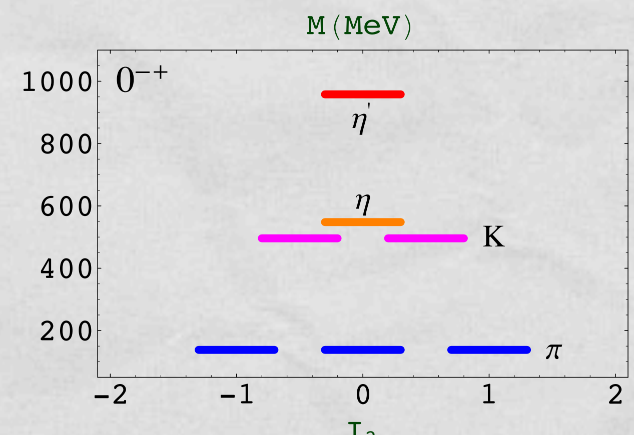
2003, THE YEAR OF THE ALTERNATING PENTAQUARK

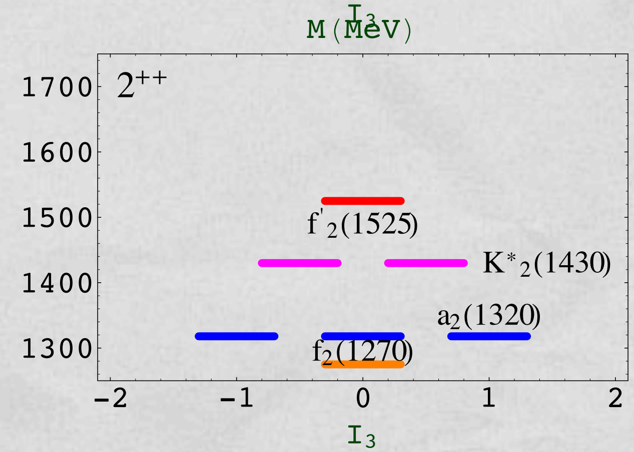
PENTA $\rightarrow$ TETRA

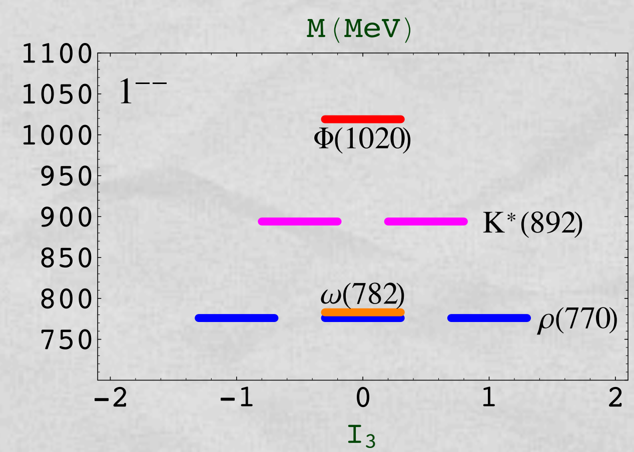
LIGHT SCALAR MESONS











Observed by R Jaffe and many others

DIQUARKS

$$R_1 \otimes R_2 = S_1 \oplus S_2$$

$$(T^a_{R_1 \otimes R_2})_{iI,jJ} = (T^a_{R_1})_{ij}\delta_{IJ} + \delta_{ij}(T^a_{R_2})_{IJ}$$

$$2\sum_a T^a_{R_1} \otimes T^a_{R_2} = (C(S_1) - C(R_1) - C(R_2))\mathbb{1}_{S_1}$$

$$\oplus\ (C(S_2) - C(R_1) - C(R_2))\mathbb{1}_{S_2}$$

1	3*	6	8
-4/3	-2/3	+1/3	+1/6

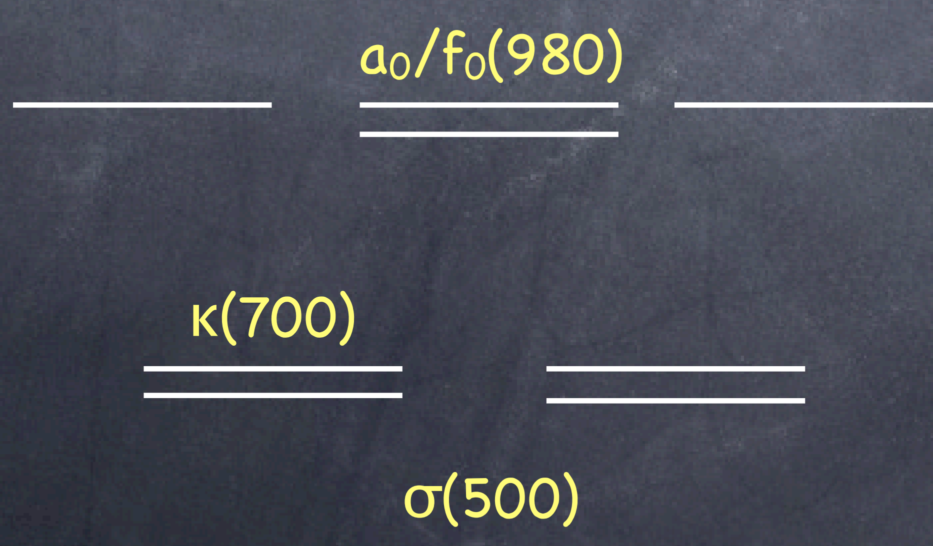
Diquark Exoticity

$$q \mapsto \bar{\mathfrak{q}}$$
$$\bar{q} \mapsto \mathfrak{q}$$

$$\mathfrak{q} = [q\uparrow q\downarrow]_{\bar{\mathbf{3}}_{\mathbf{c}},\bar{\mathbf{3}}_{\mathbf{f}}} \text{ or, more precisely, } \mathfrak{q}_{i\alpha} = \epsilon_{ijk}\epsilon_{\alpha\beta\gamma}\bar{q}_C^{j\beta}\gamma_5 q^{k\gamma}$$

with such a notation we would write

$$\begin{aligned}
\sigma &= \mathfrak{q}^3\bar{\mathfrak{q}}^3;\ \text{where } 1,2,3 = u,d,s \\
\kappa &= \mathfrak{q}^2\bar{\mathfrak{q}}^3,\ \mathfrak{q}^1\bar{\mathfrak{q}}^3,\ +\text{ conj. doubl.} \\
f_0 &= \frac{\mathfrak{q}^2\bar{\mathfrak{q}}^2 + \mathfrak{q}^1\bar{\mathfrak{q}}^1}{\sqrt{2}} \\
a_0 &= \mathfrak{q}^2\bar{\mathfrak{q}}^1,\ \frac{\mathfrak{q}^2\bar{\mathfrak{q}}^2 - \mathfrak{q}^1\bar{\mathfrak{q}}^1}{\sqrt{2}},\ \mathfrak{q}^1\bar{\mathfrak{q}}^2
\end{aligned}$$



$$\underbrace{[ds][\bar{u}\bar{s}]}_{I_3=-1}\quad \underbrace{[us][\bar{u}\bar{s}],[sd][\bar{s}\bar{d}]}_{I_3=0}\quad \underbrace{[us][\bar{d}\bar{s}]}_{I_3=+1}$$

$$\underbrace{[ud][\bar{u}\bar{s}],[sd][\bar{u}\bar{d}]}_{I_3=-1/2}\quad \underbrace{[ud][\bar{d}\bar{s}],[us][\bar{u}\bar{d}]}_{I_3=+1/2}$$

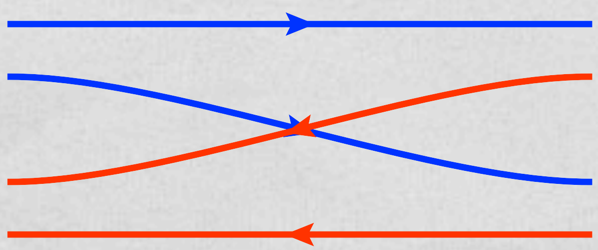
$$\underbrace{[ud][\bar{u}\bar{d}]}_{I_3=0}$$

HOW DOES F0 DECAY?

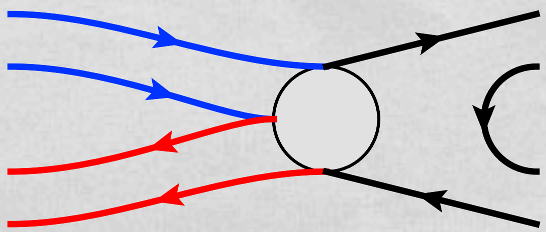
't Hooft, Isidori, Maiani, Polosa, Riquer, Phys Lett B 2008

The f0(980), [us][u*s*] is known to decay mostly in two pions; the kaon channel being closed by phase space.

$$\mathcal{L}_1 = g_1 S^i{}_j \epsilon_{i\ell k} \epsilon^{jmn} \partial_\mu \Pi^\ell_m \partial^\mu \Pi^k_n$$

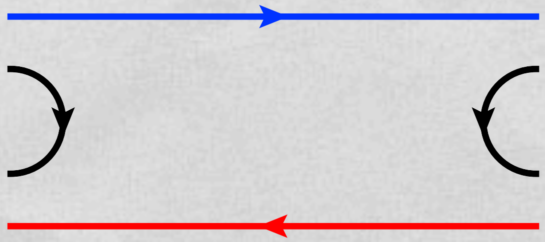


$$\mathcal{L}_2 = g_2 \mathrm{Tr}\ S \partial_\mu \Pi \partial^\mu \Pi$$



6-fermion interaction induced by instantons.

vs. double annihilation



$$\mathcal{L}_1 \propto \mathrm{Tr}(S\partial_\mu \Pi \partial^\mu \Pi) - \frac{1}{2}\mathrm{Tr}S\ \mathrm{Tr}(\partial_\mu \Pi \partial^\mu \Pi)$$

$$\mathcal{L}^{4q} = c_F \mathcal{L}_1 + c_I \mathcal{L}_2$$

$$\mathcal{L}^{2q} = c'_F \mathcal{L}_2$$

BEST FIT

't Hooft, Isidori, Maiani, Polosa, Riquer, Phys Lett B 2008

Why not simply invoking the annihilation of strange quarks?
Annihilation would mean 1-the breaking of diquarks 2-the annihilation of strange quarks.
Instantanton induced interactions proceed directly from the diquarks.
Yet the effective treatment of the problem is at the meson level.

Processes	$\mathcal{A}_{\rm th}([qq][\bar{q}\bar{q}])$			$\mathcal{A}_{\rm th}(q\bar{q})$		$\mathcal{A}_{\rm expt}$
	with inst.	no inst.	best fit	with inst.	no inst.	
$\sigma \to \pi^+\pi^-$	input	input	1.6	input	input	3.22 ± 0.04
$\kappa^+ \to K^0\pi^+$	7.3	7.7	3.3	6.0	5.5	5.2 ± 0.1
$f_0 \to \pi^+\pi^-$	input	[0–1.6]	1.6	input	[0–1.6]	1.4 ± 0.6
$f_0 \to K^+K^-$	6.7	6.4	3.5	6.4	6.4	3.8 ± 1.1
$a_0 \to \pi^0\eta$	6.7	7.6	2.7	12.4	11.8	2.8 ± 0.1
$a_0 \to K^+K^-$	4.9	5.2	2.2	4.1	3.7	2.16 ± 0.04

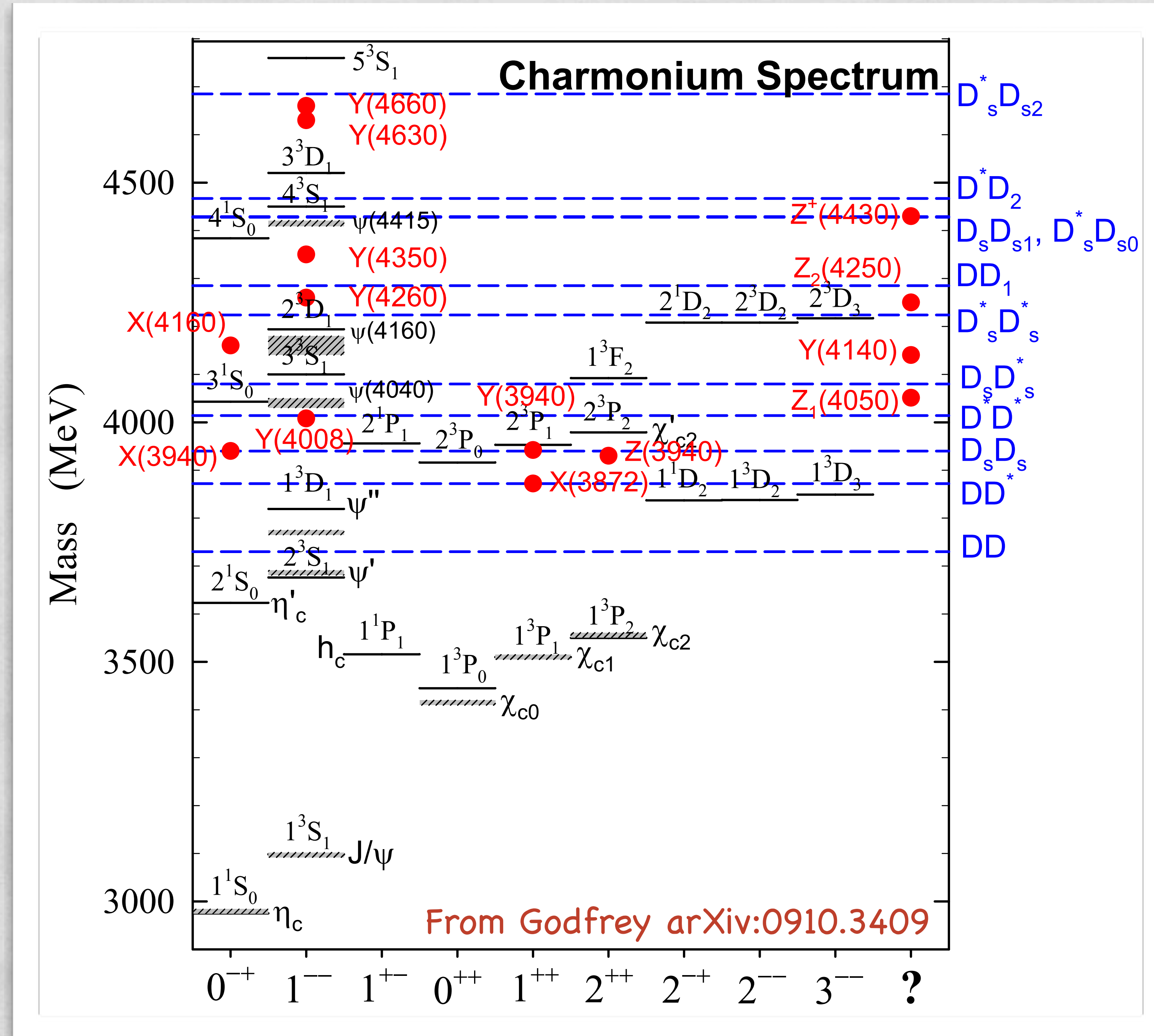
This is the first global fit which works.

XYZ, THE NEW CHARM SPECTROSCOPY

arXiv:1010.5827

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)	Experiment (#σ)	Year	Status
$X(3872)$	3871.52±0.20	1.3±0.6	$1^{++}/2^{-+}$	$B \to K(\pi^+\pi^- J/\psi)$	Belle [85, 86] (12.8), BABAR [87] (8.6)	2003	OK
		(<2.2)		$p\bar{p} \to (\pi^+\pi^- J/\psi) + ...$	CDF [88–90] (np), DØ [91] (5.2)		
				$B \to K(\omega J/\psi)$	Belle [92] (4.3), BABAR [93] (4.0)		
				$B \to K(D^{*0}\bar{D}^0)$	Belle [94, 95] (6.4), BABAR [96] (4.9)		
				$B \to K(\gamma J/\psi)$	Belle [92] (4.0), BABAR [97, 98] (3.6)		
				$B \to K(\gamma\psi(2S))$	BABAR [98] (3.5), Belle [99] (0.4)		
$X(3915)$	3915.6 ± 3.1	28±10	$0/2^{?+}$	$B \to K(\omega J/\psi)$	Belle [100] (8.1), BABAR [101] (19)	2004	OK
				$e^+e^- \to e^+e^-(\omega J/\psi)$	Belle [102] (7.7)		
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	$e^+e^- \to J/\psi(D\bar{D}^*)$	Belle [103] (6.0)	2007	NC!
				$e^+e^- \to J/\psi\ (...)$	Belle [54] (5.0)		
$G(3900)$	3943 ± 21	52±11	1^{--}	$e^+e^- \to \gamma(D\bar{D})$	BABAR [27] (np), Belle [21] (np)	2007	OK
$Y(4008)$	4008^{+121}_{-49}	226±97	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$	Belle [104] (7.4)	2007	NC!
$Z_1(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	?	$B \to K(\pi^+\chi_{c1}(1P))$	Belle [105] (5.0)	2008	NC!
$Y(4140)$	4143.4 ± 3.0	15^{+11}_{-7}	$?^{?+}$	$B \to K(\phi J/\psi)$	CDF [106, 107] (5.0)	2009	NC!
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$?^{?+}$	$e^+e^- \to J/\psi(D\bar{D}^*)$	Belle [103] (5.5)	2007	NC!
$Z_2(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	?	$B \to K(\pi^+\chi_{c1}(1P))$	Belle [105] (5.0)	2008	NC!
$Y(4260)$	4263 ± 5	108±14	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$	BABAR [108, 109] (8.0)	2005	OK
					CLEO [110] (5.4)		
					Belle [104] (15)		
				$e^+e^- \to (\pi^+\pi^- J/\psi)$	CLEO [111] (11)		
				$e^+e^- \to (\pi^0\pi^0 J/\psi)$	CLEO [111] (5.1)		
$Y(4274)$	$4274.4^{+8.4}_{-6.7}$	32^{+22}_{-15}	$?^{?+}$	$B \to K(\phi J/\psi)$	CDF [107] (3.1)	2010	NC!
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0,2^{++}$	$e^+e^- \to e^+e^-(\phi J/\psi)$	Belle [112] (3.2)	2009	NC!
$Y(4360)$	4353 ± 11	96±42	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- \psi(2S))$	BABAR [113] (np), Belle [114] (8.0)	2007	OK
$Z(4430)^+$	4443^{+24}_{-18}	107^{+113}_{-71}	?	$B \to K(\pi^+\psi(2S))$	Belle [115, 116] (6.4)	2007	NC!
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$e^+e^- \to \gamma(\Lambda_c^+\Lambda_c^-)$	Belle [25] (8.2)	2007	NC!
$Y(4660)$	4664±12	48±15	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- \psi(2S))$	Belle [114] (5.8)	2007	NC!
$Y_b(10888)$	10888.4±3.0	$30.7^{+8.9}_{-7.7}$	1^{--}	$e^+e^- \to (\pi^+\pi^- \Upsilon(nS))$	Belle [37, 117] (3.2)	2010	NC!

WE THOUGHT TO KNEW EVERYTHING ABOUT CHARMONIUM ...



... but then (2004/5) the red dots came about

Wednesday, September 21, 11

HEAVY-LIGHT TETRAQUARKS

Maiani, Piccinini, Polosa, Riquer, Phys. Rev. D71, 014028 (2005)

Light diquarks are favored in spin zero. But because of HQS this is not the case for an heavy light diquark. We could build 1^{++} states!

All the mesons (red dots) in the table are NEUTRAL particles whereas the tetraquark model predicts also the existence of CHARGED particles like

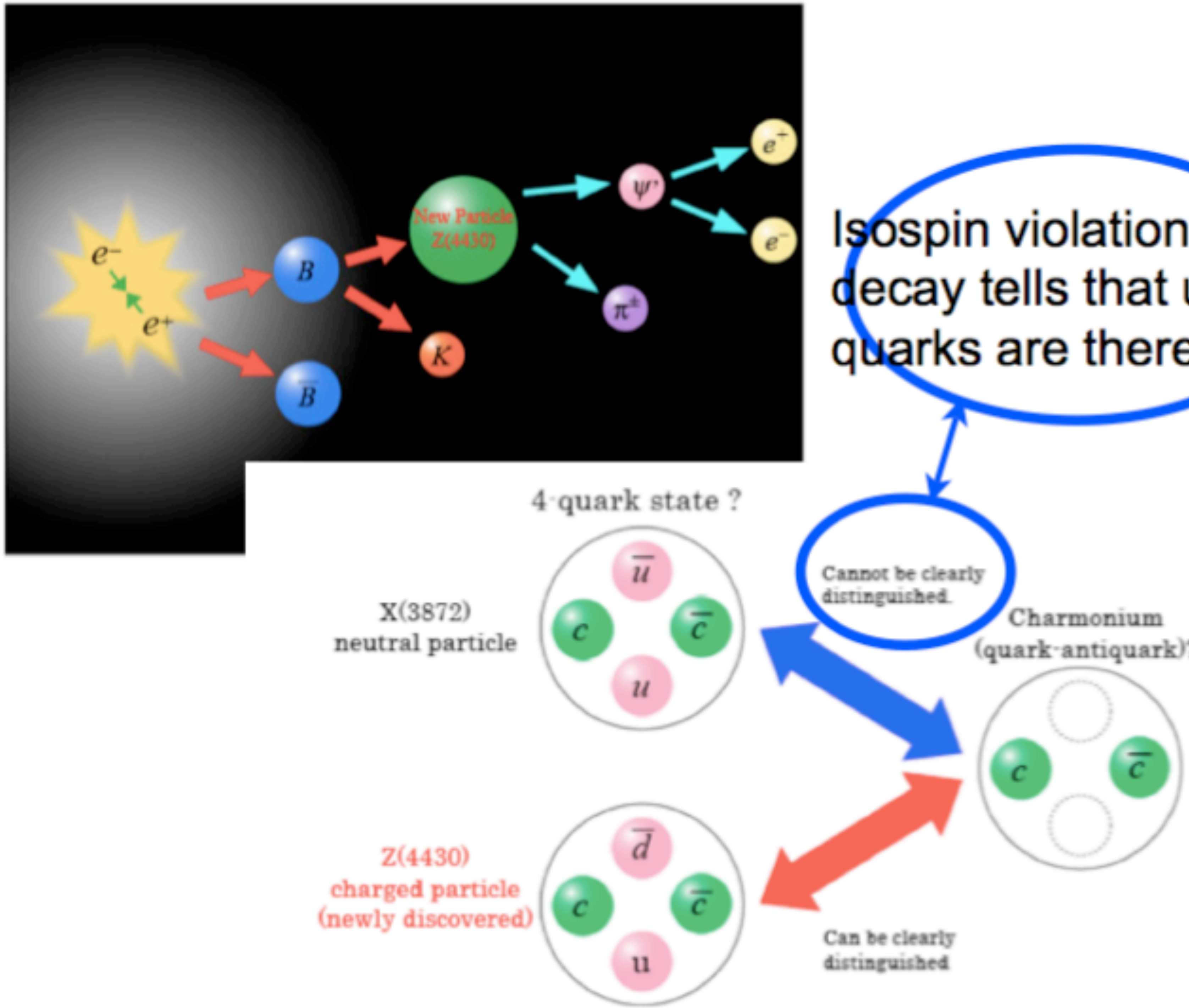
$$[cu][\bar{c}\bar{d}] \quad Q=+1$$

$$[cu][\bar{d}\bar{s}] \quad Q=+2$$

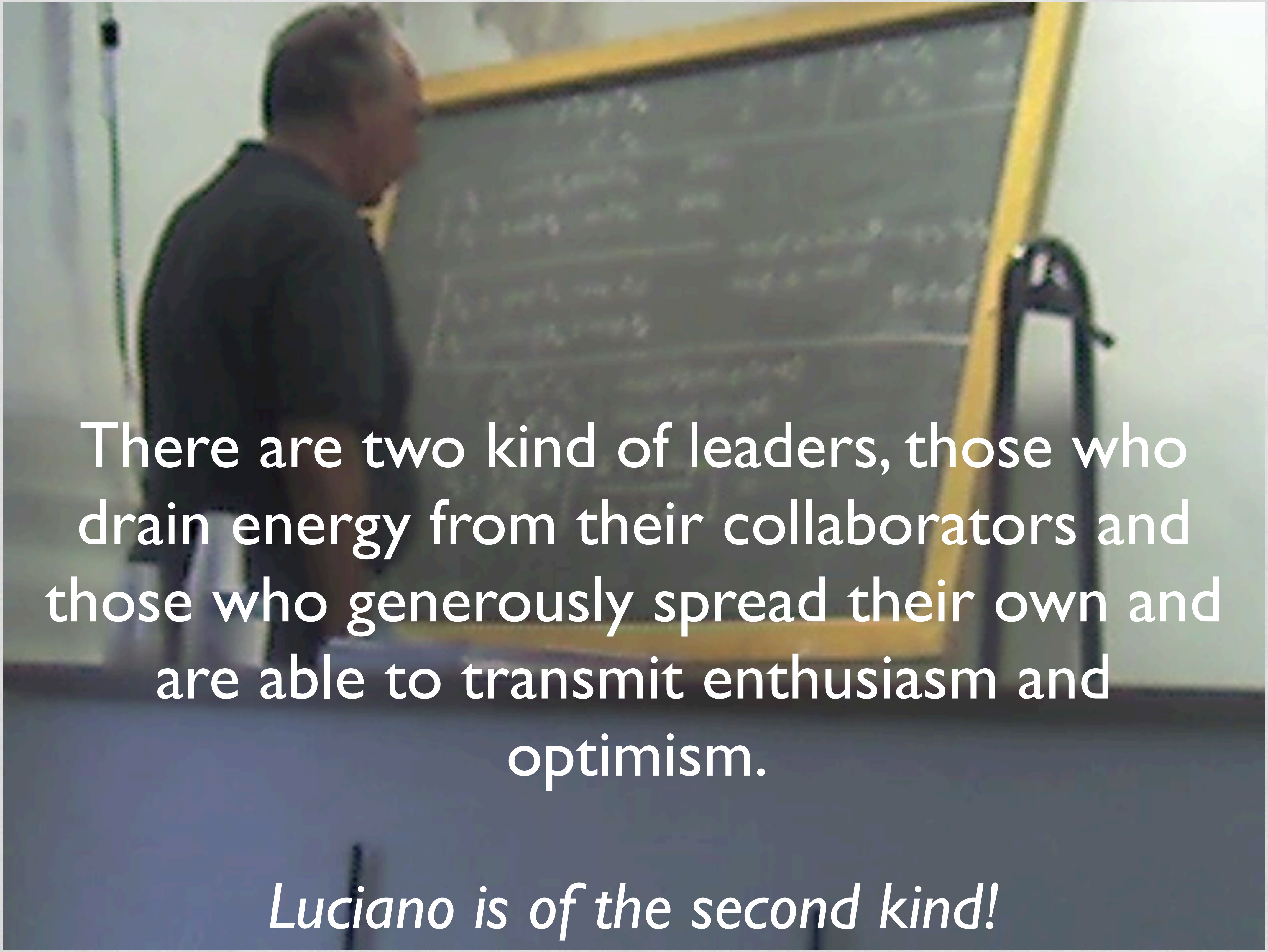
Light states like

$$[uu][\bar{d}\bar{s}] \quad Q=+2$$

are disfavored as the spin one light diquark is itself disfavored



Isospin violation in decay tells that u&d quarks are there


There are two kind of leaders, those who drain energy from their collaborators and those who generously spread their own and are able to transmit enthusiasm and optimism.
Luciano is of the second kind!

23 November 2000

PHYSICS LETTERS B

ELSEVIER

Physics Letters B 494 (2000) 168–174

www.elsevier.nl/locate/npe

Predicting $D \to \sigma\pi$

R. Gatto [a,*], G. Nardulli [b], A.D. Polosa [c], N.A. Törnqvist [c]

[a] *Département de Physique Théorique, Université de Genève, 24 quai E.-Ansermet, CH-1211 Genève 4, Switzerland*
[b] *Dipartimento di Fisica, Università di Bari and INFN Bari, via Amendola 173, I-70126 Bari, Italy*
[c] *Physics Department, POB 9, FIN-00014, University of Helsinki, Helsinki, Finland*

Received 21 September 2000; accepted 7 October 2000
Editor: L. Alvarez-Gaumé

$B \to \rho\pi$ Decays, Resonant and Nonresonant Contributions

A. Deandrea[1] and A. D. Polosa[2]

[1]*Theory Division, CERN, CH-1211 Genève 23, Switzerland*
[2]*Physics Department, University of Helsinki, POB 9, FIN-00014, Helsinki, Finland*

(Received 10 August 2000)

We point out that a new contribution to B decays to three pions is relevant in explaining recent data from the CLEO and BABAR Collaborations, in particular, the results on quasi-two-body decays via a ρ meson. We also discuss the relevance of these contributions to the measurement of CP violations.

DOI: 10.1103/PhysRevLett.86.216

15 March 2001

PHYSICS LETTERS B

ELSEVIER

Physics Letters B 502 (2001) 79–86

www.elsevier.nl/locate/npe

The $s\bar{s}$ and $K\overline{K}$ nature of $f_0(980)$ in D_s decays

A. Deandrea [a], R. Gatto [b], G. Nardulli [c], A.D. Polosa [d], N.A. Törnqvist [d]

[a] *Institut de Physique Nucléaire, Université Lyon I, 43, bd du 11 Novembre 1918, F-69622 Villeurbanne Cedex, France*
[b] *Département de Physique Théorique, Université de Genève, 24 quai E.-Ansermet, CH-1211 Genève 4, Switzerland*
[c] *Dipartimento di Fisica, Università di Bari and INFN Bari, via Amendola 173, I-70126 Bari, Italy*
[d] *Physics Department, P.O.B. 9, FIN-00014, University of Helsinki, Helsinki, Finland*

Received 10 December 2000; accepted 26 January 2001
Editor: L. Alvarez-Gaumé

VOLUME 93, NUMBER 21 PHYSICAL REVIEW LETTERS week ending 19 NOVEMBER 2004

New Look at Scalar Mesons

L. Maiani*
Università di Roma "La Sapienza" and I.N.F.N., Roma, Italy

F. Piccinini†
I.N.F.N. Sezione di Pavia and Dipartimento di Fisica Nucleare e Teorica, via A. Bassi, 6, I-27100, Pavia, Italy

A. D. Polosa‡
Centro Studi e Ricerche "E. Fermi," via Panisperna 89/A-00184 Roma, Italy

V. Riquer§
CERN Theory Department, CH-1211, Switzerland
(Received 1 July 2004; published 16 November 2004)

Light scalar mesons are found to fit rather well a diquark-antidiquark description. The resulting nonet obeys mass formulas which respect, to a good extent, the Okubo-Zweig-Iizuka (OZI) rule. OZI allowed strong decays are reasonably reproduced by a single amplitude describing the switch of a $q\bar{q}$ pair, which transforms the state into two colorless pseudoscalar mesons. Predicted heavy states with one or more quarks replaced by charm or beauty are briefly described; they should give rise to narrow states with exotic quantum numbers.

DOI: 10.1103/PhysRevLett.93.212002 PACS numbers: 12.39.–x, 12.38.–t

ELSEVIER

Available online at www.sciencedirect.com
ScienceDirect

Physics Letters B 662 (2008) 424–430

PHYSICS LETTERS B

www.elsevier.com/locate/physletb

A theory of scalar mesons

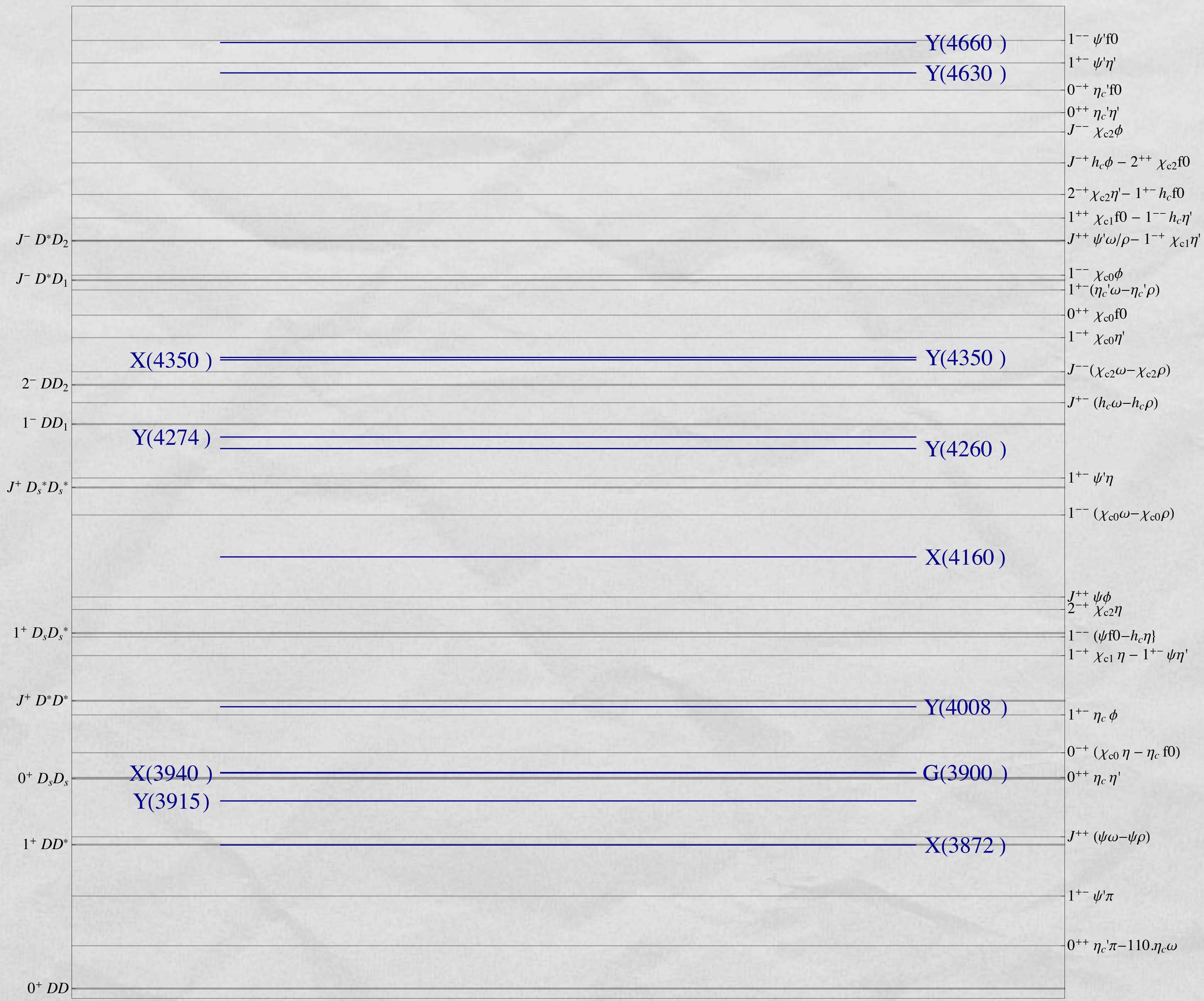
G. 't Hooft [a], G. Isidori [b,c], L. Maiani [d,e], A.D. Polosa [e,*], V. Riquer [e]

[a] *Institute for Theoretical Physics, Utrecht University, and Spinoza Institute, Postbus 8000, 3508 TA Utrecht, The Netherlands*
[b] *Scuola Normale Superiore, Piazza dei Cavalieri 7, 56126 Pisa, Italy*
[c] *INFN, Laboratori Nazionali di Frascati, Via E.Fermi 40, 00044 Frascati, Italy*
[d] *Dipartimento di Fisica, Università di Roma "La Sapienza", P.le A. Moro 2, 00185 Roma, Italy*
[e] *INFN, Sezione di Roma "La Sapienza", P.le A. Moro 2, 00185 Roma, Italy*

Received 18 January 2008; received in revised form 15 February 2008; accepted 18 March 2008

Available online 21 March 2008

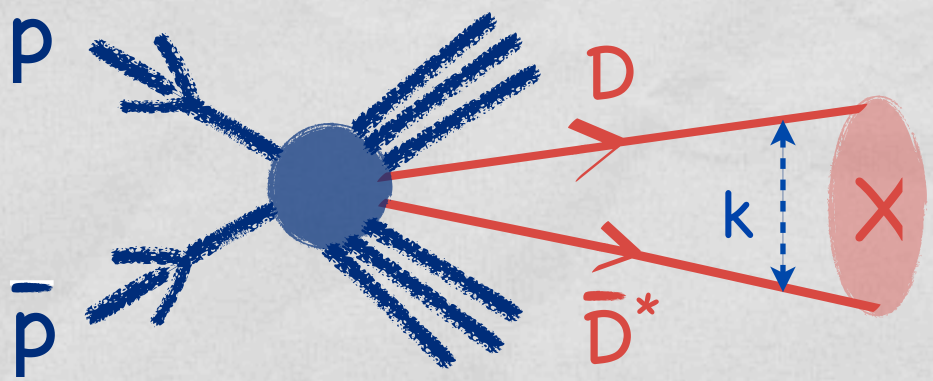
Editor: G.F. Giudice



Y(4660)
Y(4630)
X(4350)
Y(4350)
Y(4274)
Y(4260)
X(4160)
Y(4008)
X(3940)
G(3900)
Y(3915)
X(3872)
J⁻ D*D_2
J⁻ D*D_1
2⁻ DD_2
1⁻ DD_1
J⁺ D_s*D_s*
1⁺ D_sD_s*
J⁺ D*D*
0⁺ D_sD_s
1⁺ DD*
0⁺ DD
1⁻⁻ ψ'f0
1⁺⁻ ψ'η'
0⁻⁺ η_c'f0
0⁺⁺ η_c'η'
J⁻⁻ χ_c2φ
J⁻⁺ h_cφ – 2⁺⁺ χ_c2f0
2⁻⁺ χ_c2η'– 1⁺⁻ h_cf0
1⁺⁺ χ_c1f0 – 1⁻⁻ h_cη'
J⁺⁺ ψ'ω/ρ– 1⁻⁺ χ_c1η'
1⁻⁻ χ_c0φ
1⁺⁻(η_c'ω–η_c'ρ)
0⁺⁺ χ_c0f0
1⁻⁺ χ_c0η'
J⁻⁻(χ_c2ω–χ_c2ρ)
J⁺⁻ (h_cω–h_cρ)
1⁺⁻ ψ'η
1⁻⁻ (χ_c0ω–χ_c0ρ)
J⁺⁺ ψφ
2⁻⁺ χ_c2η
1⁻⁻ (ψf0–h_cη}
1⁻⁺ χ_c1 η – 1⁺⁻ ψη'
1⁺⁻ η_c φ
0⁻⁺ (χ_c0 η – η_c f0)
0⁺⁺ η_c η'
J⁺⁺ (ψω–ψρ)
1⁺⁻ ψ'π
0⁺⁺ η_c'π–110.η_cω

PROMPT PRODUCTION

Bignamini,Grinstein, Piccinini, Polosa, Sabelli Phys Rev Lett 2009



$$\sigma(p\bar{p} \to X(3872)) \sim \left| \int d^3k \langle X | D\bar{D}^*(\mathbf{k}) \rangle \langle D\bar{D}^*(\mathbf{k}) | p\bar{p} \rangle \right|^2$$

$$\simeq \left| \int_{\mathcal{R}} d^3k \langle X | D\bar{D}^*(\mathbf{k}) \rangle \langle D\bar{D}^*(\mathbf{k}) | p\bar{p} \rangle \right|^2$$

$$\leq \int_{\mathcal{R}} d^3k |\psi(\mathbf{k})|^2 \int_{\mathcal{R}} d^3k |\langle D\bar{D}^*(\mathbf{k}) | p\bar{p} \rangle|^2$$

$$\leq \int_{\mathcal{R}} d^3k |\langle D\bar{D}^*(\mathbf{k}) | p\bar{p} \rangle|^2$$

Using Pythia & Herwig we can compute

$$\sigma_{\max}(p\bar{p} \to X(3872)) = \int_{\mathcal{R}} d^3k |\langle D\bar{D}^*(\mathbf{k}) | p\bar{p} \rangle|^2$$

where $\mathcal{R} \sim [0.40]$ MeV

as $k \sim \sqrt{2\mu(-0.25 + 0.40)} \simeq 17$ MeV