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Puzzles in charmonium decays

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Outline

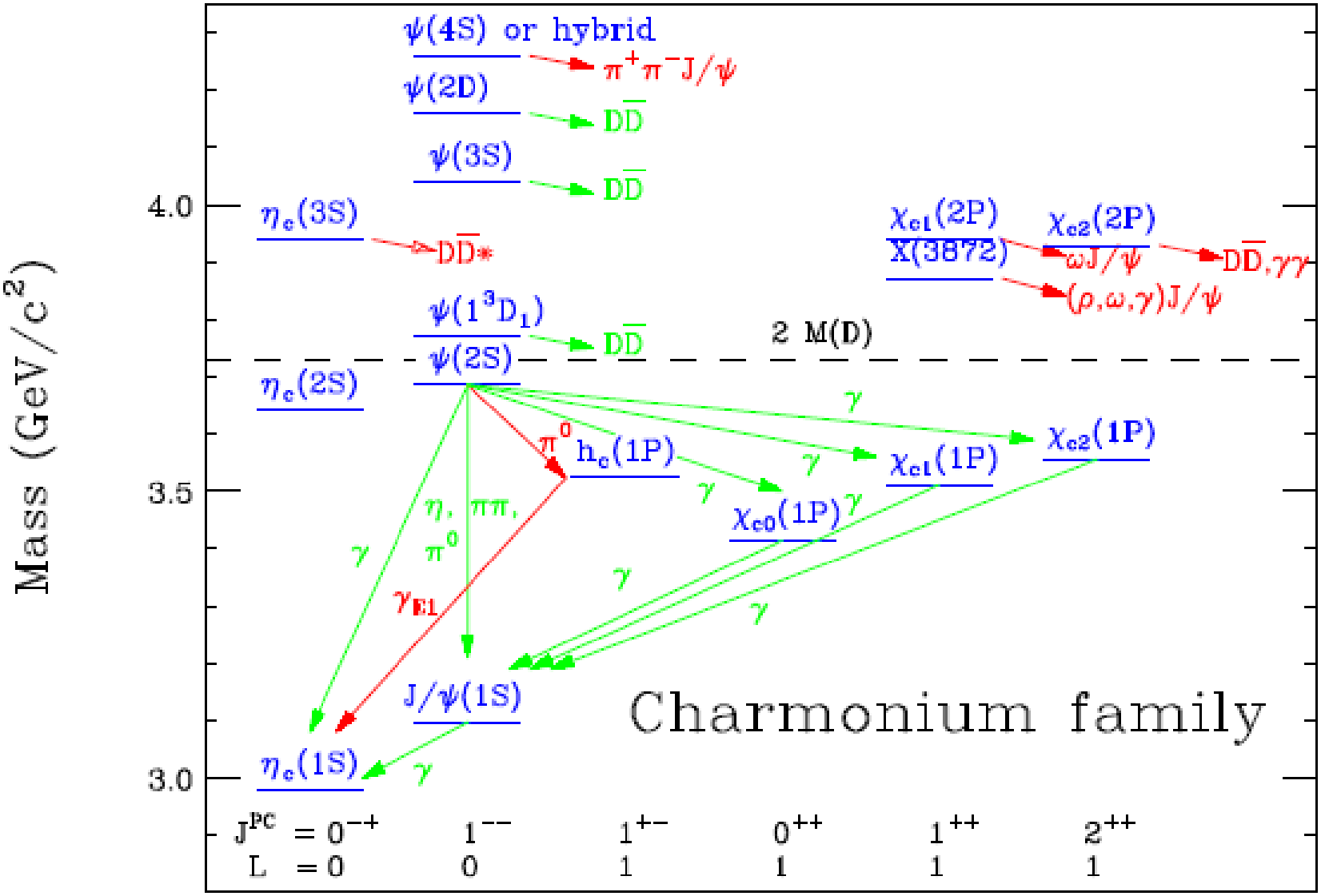
- Charmonium decays as a probe for non-perturbative mechanisms
- Exisiting puzzles in charmonium decays
- France-China Collaboration on theoretical hadron physics

Focus of hadron physics

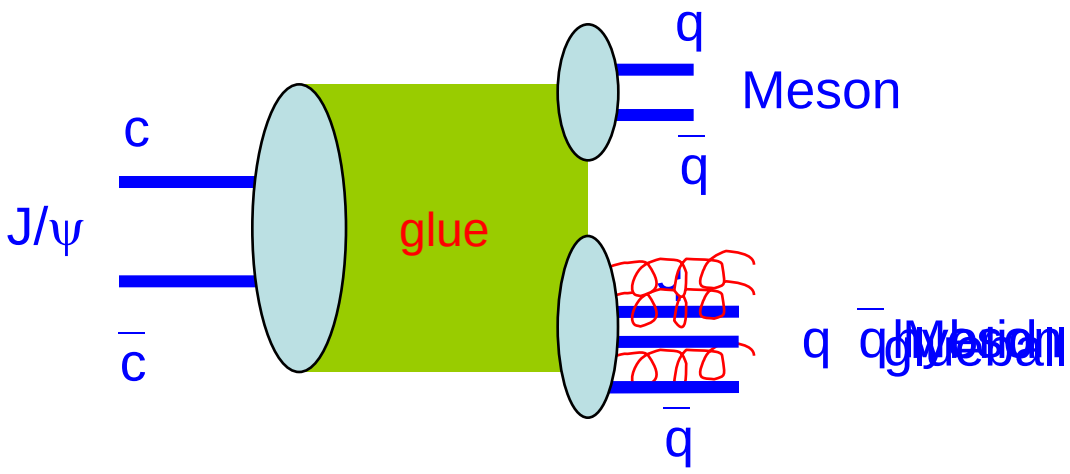
- **Complexity of QCD in the non-perturbative regime**

  exotic hadrons (glueball, hybrid, multiquarks …)
- **Lattice QCD, QCD sum rules, effective theory… Phenomenological tools**
- **Break-down certain problems**
- **Experimental information: Light hadron spectroscopy (JLab, ELSA, MAMI, ERSF, Spring-8); Heavy quarkonium hadronic and EM decays (BES, CLEO-c, Belle, BaBar, LHC…)**

❑ Charmonium spectrum



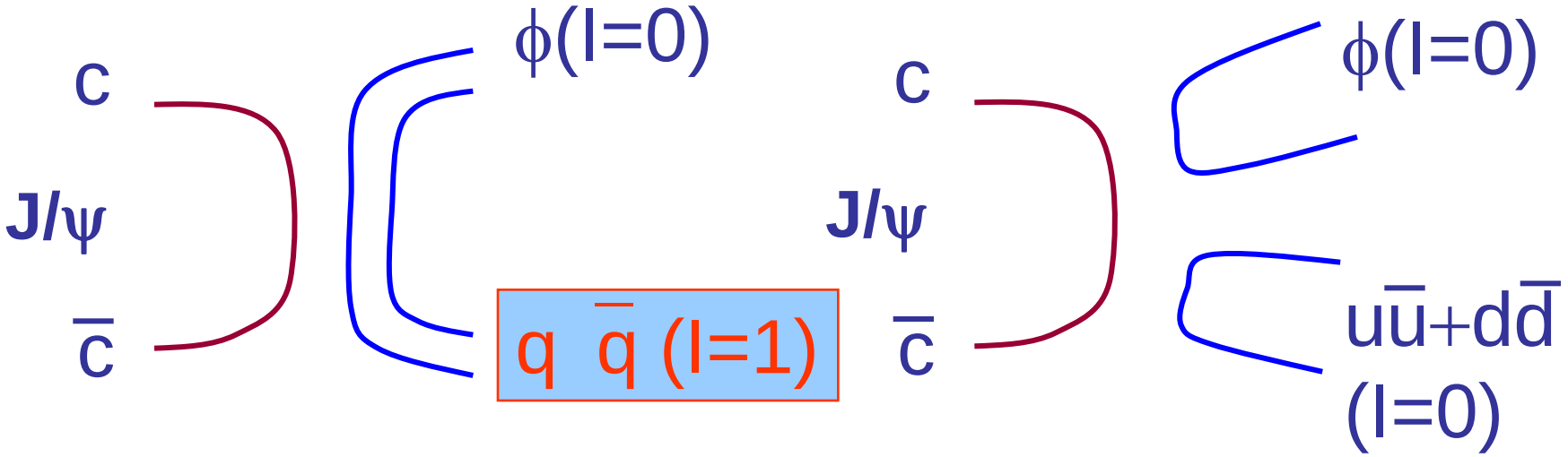
❑ A probe of strong QCD dynamics



- Glue-rich intermediate states
- Ideal for the search for exotic states (hybrid, glueball …)
- Quark-gluon interaction in light hadron production

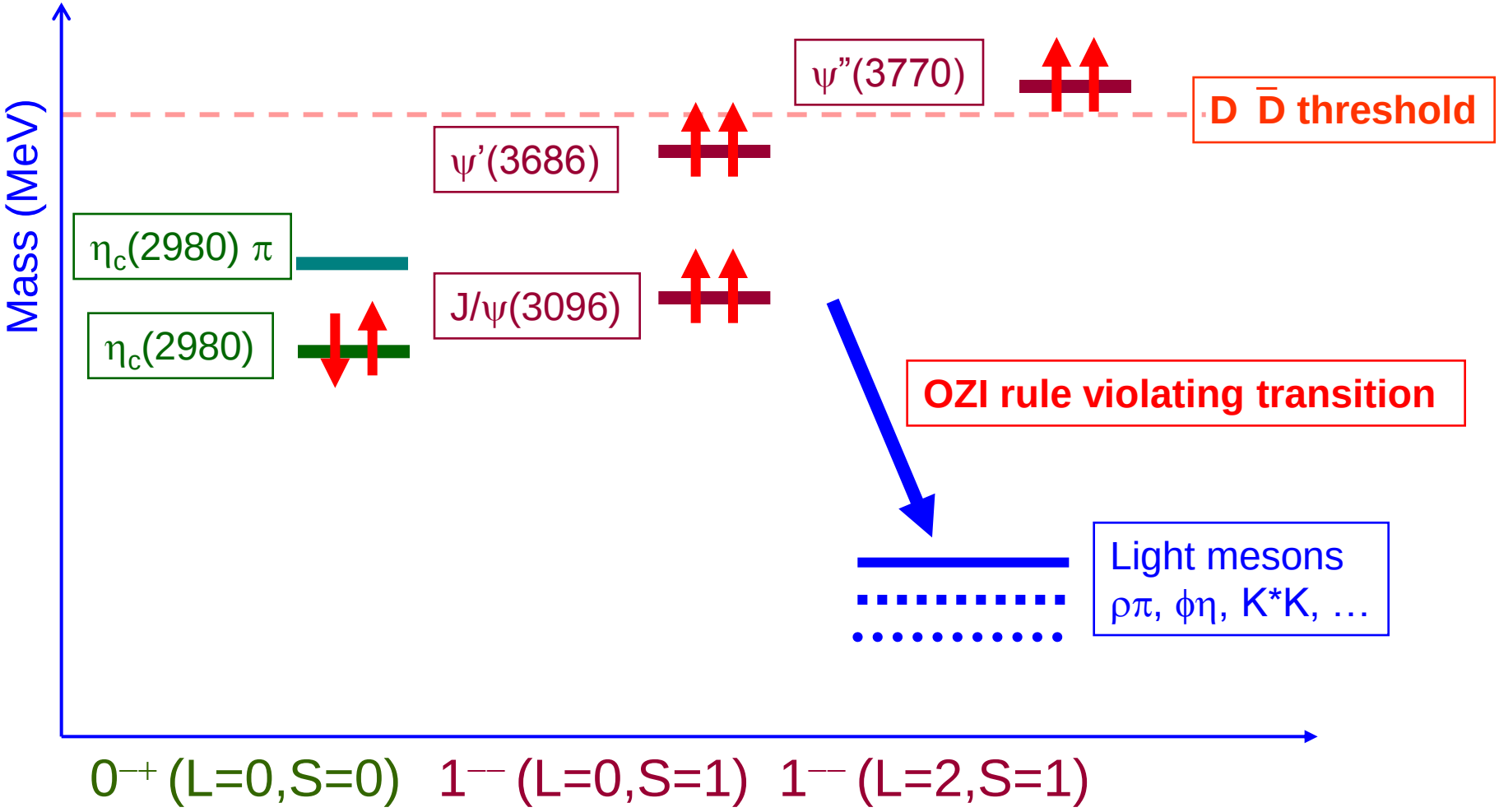
❑ A flavour filter for Okubo-Zweig-Iizuka (OZI) disconnected transitions

$$V = \begin{cases} \omega = (u\,\bar{u} + d\,\bar{d})/\sqrt{2} \\ \phi = s\,\bar{s} \end{cases}$$



- OZI rule violations
- Isospin violations

❑ Open-charm effects in charmonium decays



Several well-known puzzles in charmonium decays

- "$\rho\pi$ puzzle" in $J/\psi, \psi' \rightarrow$ VP decay
- Intermediate D meson contributions to the M1 transitions in $J/\psi, \psi' \rightarrow \gamma \eta_c, (\gamma \eta_c')$
- $\psi(3770)$ non-D $\bar{D}$ decay
- Isospin-violating decay of $\psi' \rightarrow J/\psi \pi^0$
- Hidden $c\bar{c}$ state with I=1, e.g. Z(4430), and other exotic configurations
- Scalar $a_0(980)$-$f_0(980)$ mixing in $J/\psi \rightarrow \phi f_0(980) \rightarrow \phi\pi^0\eta$
- Glueball search in charmonium hadronic decays

The open charm effects which correlated with the OZI-rule violation could be a key for understanding some of these puzzles.

❑ "ρπ puzzle" and "12% rule"

- pQCD expectation of the ratio between J/ψ and ψ' annihilation:

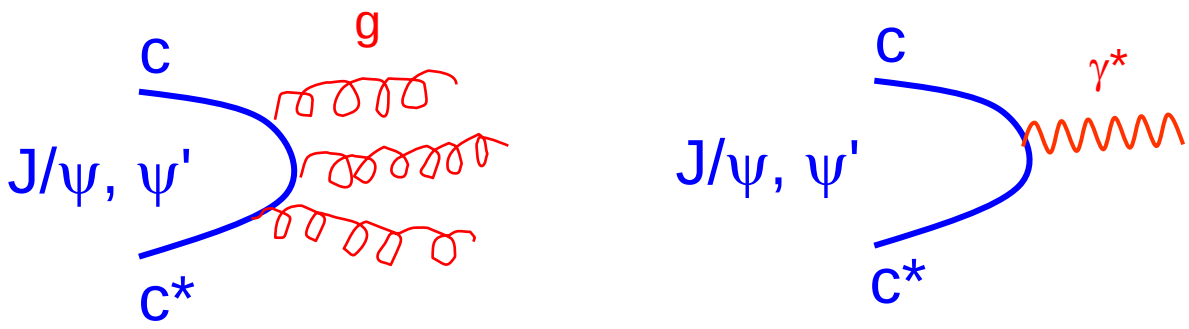
$$R \equiv \frac{BR(\psi' \to hadrons)}{BR(J/\psi \to hadrons)} \simeq \frac{BR(\psi' \to e^+e^-)}{BR(J/\psi \to e^+e^-)} \simeq 12\%,$$

- "ρπ puzzle"

$$R(\rho\pi) = \frac{(\ 3.2\ \pm 1.2\ ) \times 10^{-5}}{(\ 1.69 \pm 0.15)\ \%} \cong 0.2\ \%$$

Large "12% rule" violation in ρπ !

$\mathbf{J^{PC} = 1^{--}}$



Theoretical explanations:

1. $J/\psi \to \rho\pi$ is enhanced

- J/ψ-glueball mixing:
  Freund and Nambu, Hou and Soni, Brodsky, Lepage and Tuan
- Final state interaction:
  Li, Bugg and Zou
- Intrinsic charmonium component within light vectors:
  Brodsky and Karliner, Feldman and Kroll

2. $\psi' \to \rho\pi$ is suppressed

- Karl and Roberts: sequential fragmentation model
- Pinsky: hindered M1 transition model
- Chaichian and Tornqvist: exponential form factor model
- Chen and Braaten: color octet Fock state dominance in J/ψ
- Rosner: ψ' and ψ'' mixing

3. Others …

Recent review by Yuan et al.

Branching ratios for J/ψ (c $\bar{c}$) → V P

Γ_5	$\rho\pi$	$(\ 1.69\pm0.15)\ \%$
Γ_6	$\rho^0\pi^0$	$(\ 5.6\ \pm0.7\ )\times10^{-3}$
Γ_{14}	$K^+\overline{K}^*(892)^- + \text{c.c.}$	$(\ 5.0\ \pm0.4\ )\times10^{-3}$
Γ_{15}	$K^0\overline{K}^*(892)^0 + \text{c.c.}$	$(\ 4.2\ \pm0.4\ )\times10^{-3}$
Γ_{26}	$\omega\eta$	$(\ 1.74\pm0.20)\times10^{-3}$
Γ_{37}	$\phi\eta$	$(\ 7.4\ \pm0.8\ )\times10^{-4}$
Γ_{41}	$\phi\eta'(958)$	$(\ 4.0\ \pm0.7\ )\times10^{-4}$
Γ_{47}	$\omega\eta'(958)$	$(\ 1.82\pm0.21)\times10^{-4}$
Γ_{40}	$\omega\pi^0$	$(\ 4.5\ \pm0.5\ )\times10^{-4}$
Γ_{46}	$\rho\eta$	$(\ 1.93\pm0.23)\times10^{-4}$
Γ_{49}	$\rho\eta'(958)$	$(\ 1.05\pm0.18)\times10^{-4}$

Same order of magnitude !

- **What accounts for such a large isospin violation?**
- **Implications of the "ρπ puzzle" …**

Branching ratios for $\psi' \to$ V P

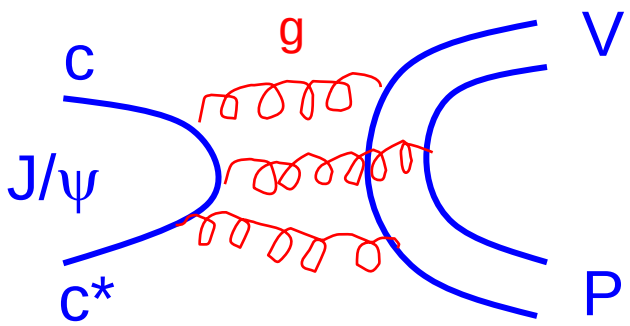
Γ_{63}	$\rho(770)\pi \to \pi^+\pi^-\pi^0$	$(3.2 \pm 1.2) \times 10^{-5}$
Γ_{67}	$K^+\overline{K}^*(892)^- +$ c.c.	$(1.7 \ ^{+0.8}_{-0.7}) \times 10^{-5}$
Γ_{68}	$K^*(892)^0\overline{K}^0 +$ c.c.	$(1.09 \pm 0.20) \times 10^{-4}$
Γ_{80}	$\omega\eta$	$< 1.1 \times 10^{-5}$
Γ_{74}	$\phi\eta$	$(2.8 \ ^{+1.0}_{-0.8}) \times 10^{-5}$
Γ_{75}	$\phi\eta'$	$(3.1 \pm 1.6) \times 10^{-5}$
Γ_{76}	$\omega\eta'$	$(3.2 \ ^{+2.5}_{-2.1}) \times 10^{-5}$
Γ_{77}	$\omega\pi^0$	$(2.1 \pm 0.6) \times 10^{-5}$
Γ_{78}	$\rho\eta'$	$(1.9 \ ^{+1.7}_{-1.2}) \times 10^{-5}$
Γ_{79}	$\rho\eta$	$(2.2 \pm 0.6) \times 10^{-5}$
Γ_{81}	$\phi\pi^0$	$< 4 \times 10^{-6}$

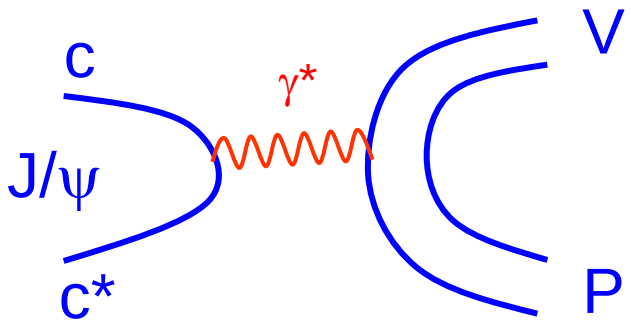
Particle Data Group

Comparable !?

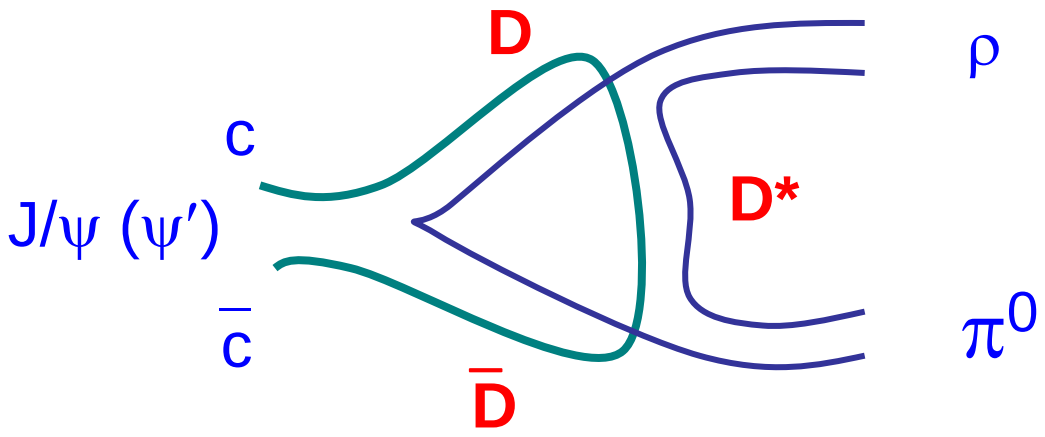
$$\frac{BR(\psi' \to \quad VP)}{BR(J/\psi \to \quad VP)} \neq \frac{BR(\psi' \to \text{3g} \to VP)}{BR(J/\psi \to \text{3g} \to VP} \quad \begin{matrix} \text{+/– EM + Long-range int.} \\ \text{+/– EM + Long-range int.} \end{matrix}$$

- "12% rule" will not hold if EM, and other possible transitions are important.



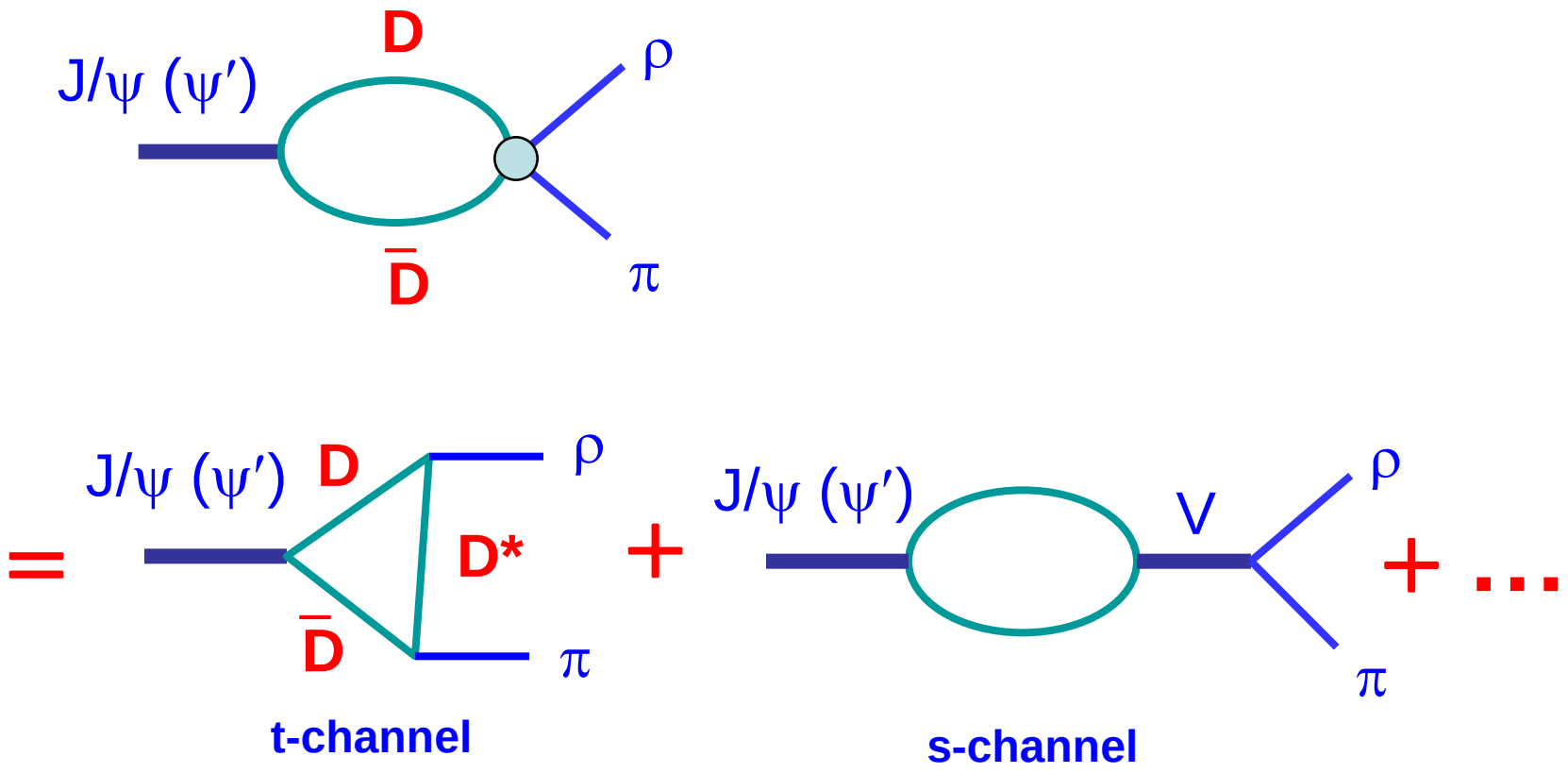


Open-charm effects as an OZI-rule evading mechanism



• Interferences among the single OZI, EM and intermediate meson loop transitions are unavoidable.

Decomposition of OZI evading long-range loop transitions



Zhang, Li and Zhao, 0902.1300[hep-ph]; Li and Zhao, PLB670, 55(2008)

Recognition of interferences

Property of the anti-symmetric tensor coupling allows a parametrization:

$$\begin{cases} \mathcal{M}_{J/\psi} = \dfrac{1}{M_{J/\psi}}(g_{J/\psi} + g^{em}_{J/\psi} e^{i\delta_{J/\psi}})\epsilon_{\mu\nu\alpha\beta}\partial^\mu V^\nu_{J/\psi}\partial^\alpha V_2^\beta P \\ \mathcal{M}_{\psi'} = \dfrac{1}{M_{\psi'}}(g_{\psi'} + g^{em}_{\psi'} e^{i\delta_{\psi'}})\epsilon_{\mu\nu\alpha\beta}\partial^\mu V^\nu_{\psi'}\partial^\alpha V_2^\beta P \ , \end{cases}$$

$$\begin{cases} g_{J/\psi} \equiv g^{pQCD}_{J/\psi} + g^{loop}_{J/\psi} \equiv g^{pQCD}_{J/\psi}(1 + q_{J/\psi}) \\ g_{\psi'} \equiv g^{pQCD}_{\psi'} + g^{loop}_{\psi'} \equiv g^{pQCD}_{\psi'}(1 + q_{\psi'}) \ , \end{cases}$$

In order to account for the "ρπ puzzle", a destructive phase between $g^{pQCD}_{\psi'}$ **and** $g^{loop}_{\psi'}$ **is favored.**

Zhao, Li, and Chang, 0812.4092[hep-ph].

Including EM and strong transitions

Zhao, Li and Chang, PLB645, 173(2007), Li, Zhao, and Chang, JPG (2008)

Decay channels	Scheme-I (%)	Scheme-II (%)	Scheme-III (%)	Exp. data (%)
$\rho\pi$	0.12	0.17	0.20	0.2 ± 0.1
$\omega\eta$	0.40	0.33	0.28	$< 0.6 \pm 0.1$
$\omega\eta'$	5.91	0.03	0.25	18.5 ± 13.2
$\phi\eta$	2.77	2.92	3.29	4.1 ± 1.6
$\phi\eta'$	4.87	6.22	9.08	8.7 ± 5.5
$K^{*+}K^- + c.c.$	0.46	0.43	0.42	0.4 ± 0.2
$K^{*0}\bar{K}^0 + c.c.$	2.70	2.67	2.57	2.7 ± 0.7
$\rho\eta$		9.37		11.5 ± 5.0
$\rho\eta'$		7.33		23.5 ± 17.8
$\omega\pi$		9.28		5.0 ± 1.8
$\phi\pi$		8.43		< 62.5

Some features about the open charm

◆ The intermediate meson loops will contribute to the real part of the couplings since both J/ψ and ψ' are below the open charm threshold.

◆ Since the ψ' has a mass which is closer to the open $D\bar{D}$ threshold, its amplitude via the $D\bar{D}$ loop will be qualitatively larger than J/ψ due to near-threshold effects.

◆ Similar behavior due to intermediate $D\bar{D}(D^*)$ and $D\bar{D}^*(D)$ loops also shows up in a coherent study of J/ψ and $\psi' \to \gamma\eta_c$ and $\psi' \to \gamma\eta'_c$. **(Li & Zhao, PLB670, 55(2008))**

◆ Light intermediate meson loops are strongly suppressed due to large off-shell effects.

◆ Open charm effects are essential for understanding ψ'' non-$D\bar{D}$ decays **(Zhang, Li & Zhao, 0902.1300[hep-ph])**

A proposal to FCPPL

New hadrons at future colliders

Coordinators: Jean-Marc Richard, Shi-Lin Zhu, Qiang Zhao

February 1, 2009

Abstract

This is a proposal to study new hadrons, ordinary and exotic, within the framework of the French and Chinese Collaboration Program, with emphasis on the heavy flavor sector, accessible in forthcoming experimental devices.

Topics

Z(4430) as tetraquark candidate, and its production mechanism; The newly reported Y(4143) into J/ψ ϕ by CDF.

- Multiflavored hadrons s
analogue, exotic meson

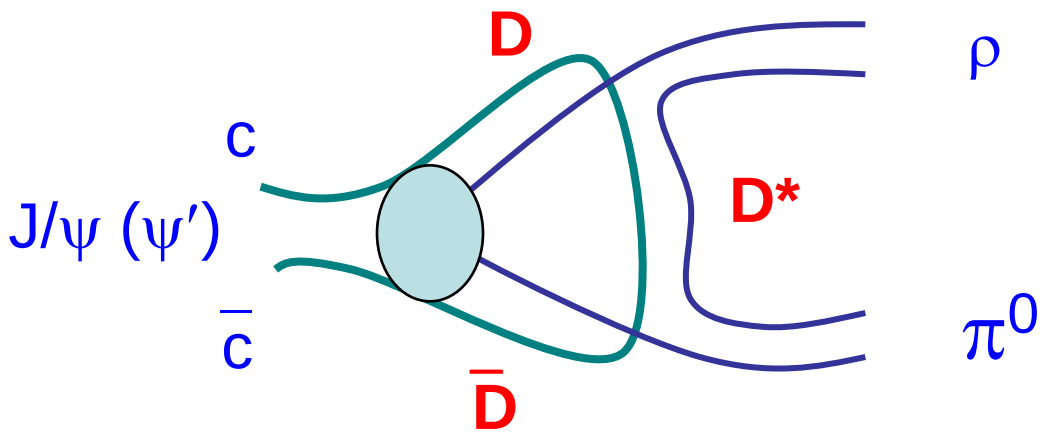
- X(3872) and other new hidden-c mesons which do fit the spectrum of orbital or radial excitation of charmonium and thus are candidate for new hadron structure such as hybrid and multiquark. This latter configuration is particularly suited for the recently discovered charged state of this family,

- The beauty analogues of these states are particularly important, since the different models proposed for hidden charge give different predictions,

- Description of supernumerous light hadrons, especially in the scalar sector, with emphasis on the states seen at BES in the decay of charmonium. These states raise the question of the gluon degrees of freedom,

Topics

- New applications of QCD sum rules, in particular to the decay properties of hybrid mesons,
- Further applications of meson–meson contributions to the production and decay properties of heavy mesons, a mechanism proposed in particular by some Chinese physicists. Some vertices involved in this approach can be estimated jointly, using QCD sum rules.



Participants

Grenoble

Prof. Jean-Marc Richard, Coordinator

Montpellier

Prof. Stephan Narison

IHEP

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Prof. Yu-Bing Dong
Prof. Peng-Nian Shen
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Prof. Ying Chen
Prof. (Associate) Yu Jia
Prof. Jian-Xiong Wang

Peking U.

Prof. Shi-Lin Zhu, Coordinator
Prof. Kuang-Ta Chao
Prof. Chuan Liu
Prof. Bo-Qiang Ma
Prof. Han-Qing Zheng

Nankai University

Prof. Xue-Qian Li

Expertise

- QCD factorization
- Quark models
- QCD phenomenology with effective Lagrangian
- QCD sum rules
- Chiral perturbation theory
- Lattice QCD

How to work together?

- **Identify commonly interested questions to involve people in this working group**
- **Regular visits between French and Chinese collaborators**

Richard and Narison visited IHEP, PKU, and Nankai U. in Dec. 2008;

Richard will visit IHEP in April 2009;

There is a plan to organize a small group meeting in the second half of 2009.

- **Involvement of PhD students**

Two PhD students from IHEP are working on a common project on exotic charmonium production;

A student of PKU will visit Montpellier for one year.

A platform

Theoretical Physics Center for Science Facilities (TPCSF), CAS

Theory Division, IHEP/CAS

Efforts full of challenges,
but we are making progress !

Thanks !

Summary

- **Rich information about the strong QCD dynamics in the correlation between the OZI evading and isospin violation.**
- **Application to J/ψ, ψ' $\rightarrow$ VP is useful for the study of "$\rho\pi$ puzzle" (Zhao, Li and Chang, PLB645, 173(2007)) and search for pseudoscalar glueball (Li, Zhao and Chang, hep-ph/0701020).**
- **Intermediate D meson contributions to the M1 transitions in J/ψ, $\psi' \rightarrow \gamma\, \eta_c$, ($\gamma\, \eta_c'$) (Li and Zhao, 0709.4639[hep-ph]).**
- **Search for glueball signals in charmonium hadronic decays (F. Close and Zhao, PRD(2005), Zhao, PRD(2007); PLB(2008))**
- **Experimental focuses of BES, CLEO-c, KLOE, B-factories…**

Key Issues in Hadronic Physics

Abstract

A group of fifty physicists met in Duck, NC, Nov. 6-9 to discuss the current status and future goals of hadronic physics. The main purpose of the meeting was to define the field by identifying its key issues, challenges, and opportunities. The conclusions, incorporating considerable input from the community at large, are presented in this white paper. [1]

Peter Barnes
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Stan Brodsky
Matthias Burkardt

Simon Capstick
Lawrence Cardman
Carl Carlson
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Barry Holstein
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Mac Mestayer
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Joel Moss

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Contributors

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Meson

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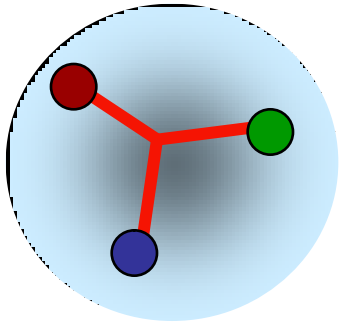
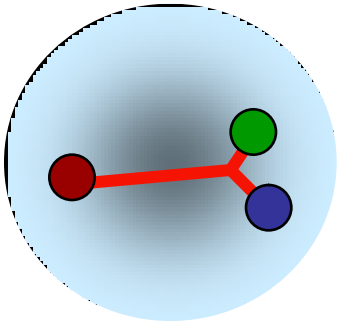
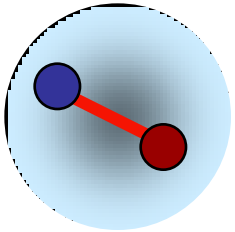


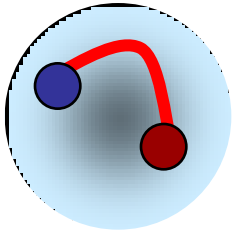
quark-diquark



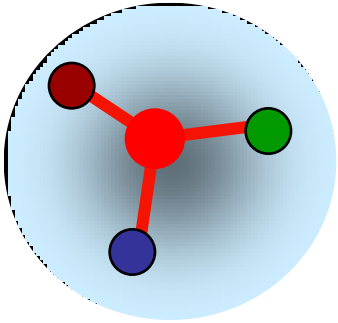


$q\ \bar{q}$

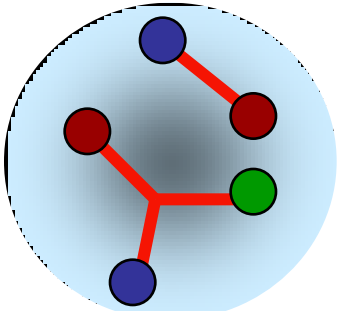
Hybrid

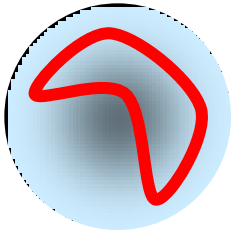


Hybrid



Pentaquark





glueball

Focus of hadron physics

- **Complexity of QCD in the non-perturbative regime**

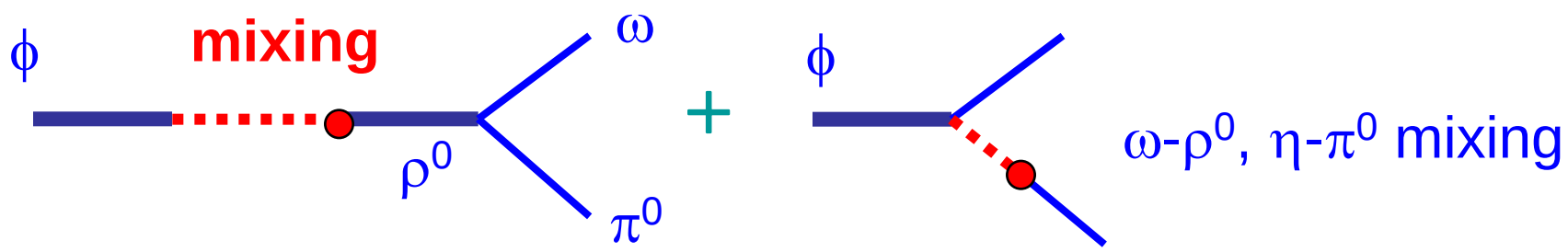
  exotic hadrons (glueball, hybrid, multiquarks …)
- **Lattice QCD, QCD sum rules, effective theory… Phenomenological tools**
- **Break-down certain problems**
- **Experimental information: Light hadron spectroscopy (JLab, ELSA, MAMI, ERSF, Spring-8); Heavy quarkonium hadronic decays (BES, CLEO-c, Belle, BaBar, LHC…)**

“ The primary goals of hadronic physics are to determine the relevant degrees of freedom that govern hadronic phenomena at all scales, to establish the connection of these degrees of freedom to the parameters and fundamental fields of QCD, and to use our understanding of QCD to quantitatively describe a wide array of hadronic phenomena, ranging from terrestrial nuclear physics to the behavior of matter in the early universe. ”

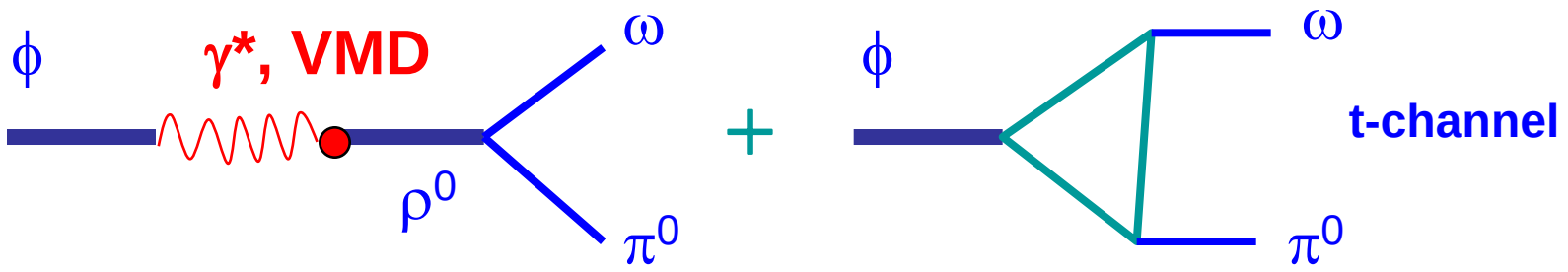
“Key issues in hadronic physics”

- **t-channel versus s-channel**

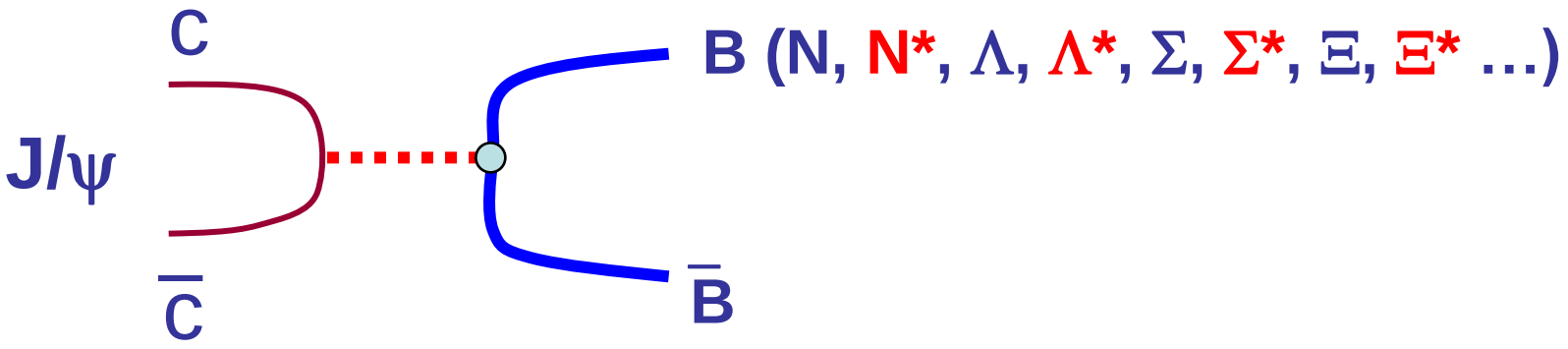
Previous approach



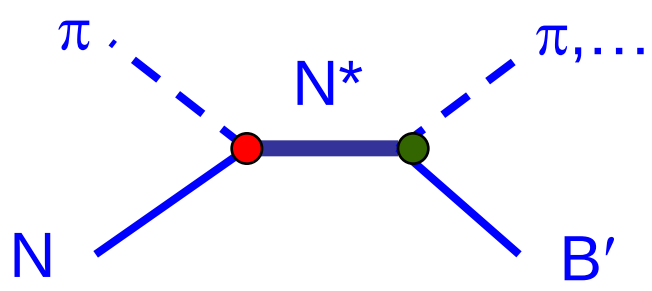
This approach

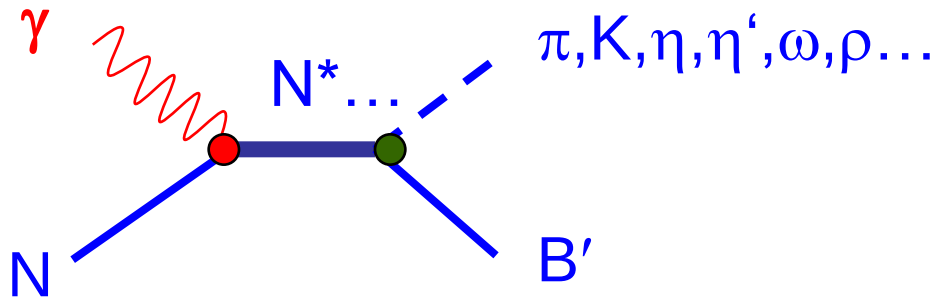


❑ A flavour filter for baryon-antibaryon production



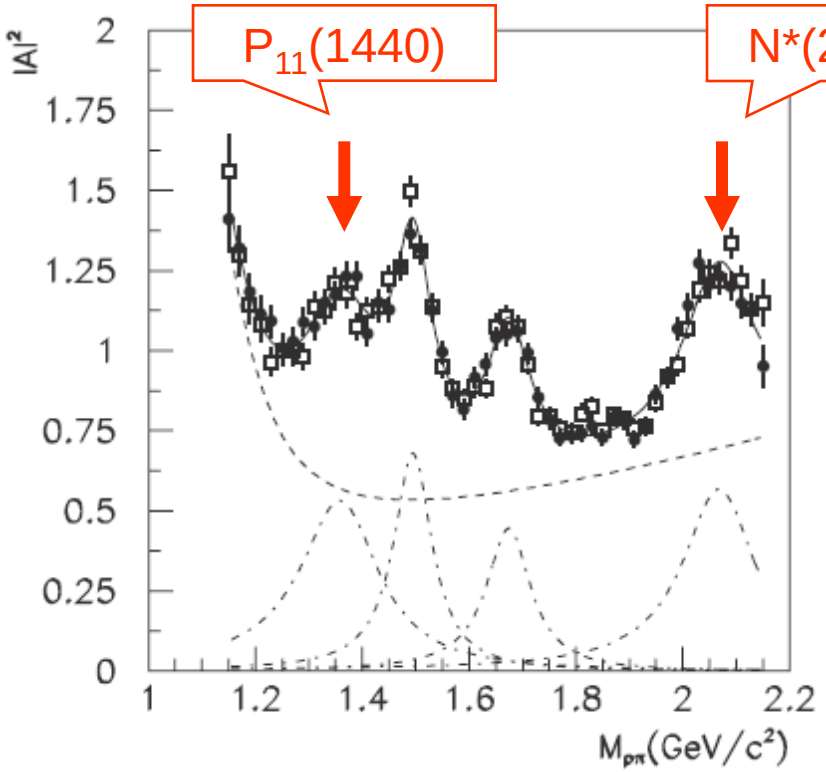
- "Missing resonances" (JLab, ELSA, ESRF, MAMI, Spring-8, …)
- Baryon form factors
- Exotic baryons





BES

$$J/\psi \to p\pi^- \bar{n} \quad \text{vs} \quad J/\psi \to \bar{p}\pi^+ n$$



N*(1440): $M = 1358 \pm 17$
$\Gamma = 179 \pm 56$

N*(2050): $M = 2068 + 15 - 40$
$\Gamma = 165 \pm 42$

pi-N invariant mass / MC phase space

BES Collaboration, Phys. Rev. Lett. 97, 062001 (2006)
"Observation of two new N* peaks …"

Zou/IHEP

Relevant issues

- **Scalar $a_0(980)$-$f_0(980)$ mixing in $J/\psi \to \phi f_0(980) \to \phi\pi^0\eta$ via OZI evading and isospin violating process (Wu, Zhao, and Zou, PRD(2007)).**
- **Application to J/ψ, $\psi' \to$ VP is useful for the study of "$\rho\pi$ puzzle" (Zhao, Li and Chang, PLB645, 173(2007)) and search for pseudoscalar glueball (**Li, Zhao and Chang, hep-ph/0701020**).**
- **Intermediate D meson contributions to the M1 transitions in J/ψ, $\psi' \to \gamma\,\eta_c$, $(\gamma\,\eta_c')$ (**Li and Zhao, 0709.4639[hep-ph] **).**
- **Search for glueball signals in charmonium hadronic decays (**F. Close and Zhao, PRD(2005), Zhao, PRD(2007); PLB(2008) **)**