Hadron spectroscopy @ future tau-charm facility

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In post-BES3 era

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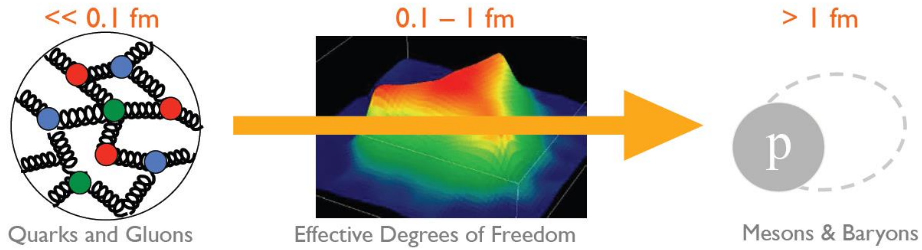
Hadron spectroscopy @ future tau-charm facility

accompanied with Belle2, GlueX, CLAS12, PANDA, COMPASS(2), ...

- Strange (charmed) baryons spectroscopy
- Hadron spectroscopy in charmonium decays (QCD exotics)
  - Glueballs
  - Hybrids
  - Multiquarks
  - N* programs
- Hadron spectroscopy in/out from charm Dalitz plot analysis
- Rare phenomena of light hadrons
- Two-photon process, ISR production are not discussed.

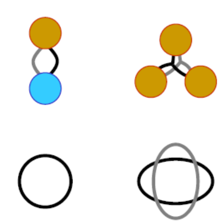
Hadron spectroscopy is a key tool to investigate QCD
- testing QCD in the confinement regime
- providing insights into the fundamental degrees of freedom



One open question: How does glue manifest itself in the soft QCD regime?"

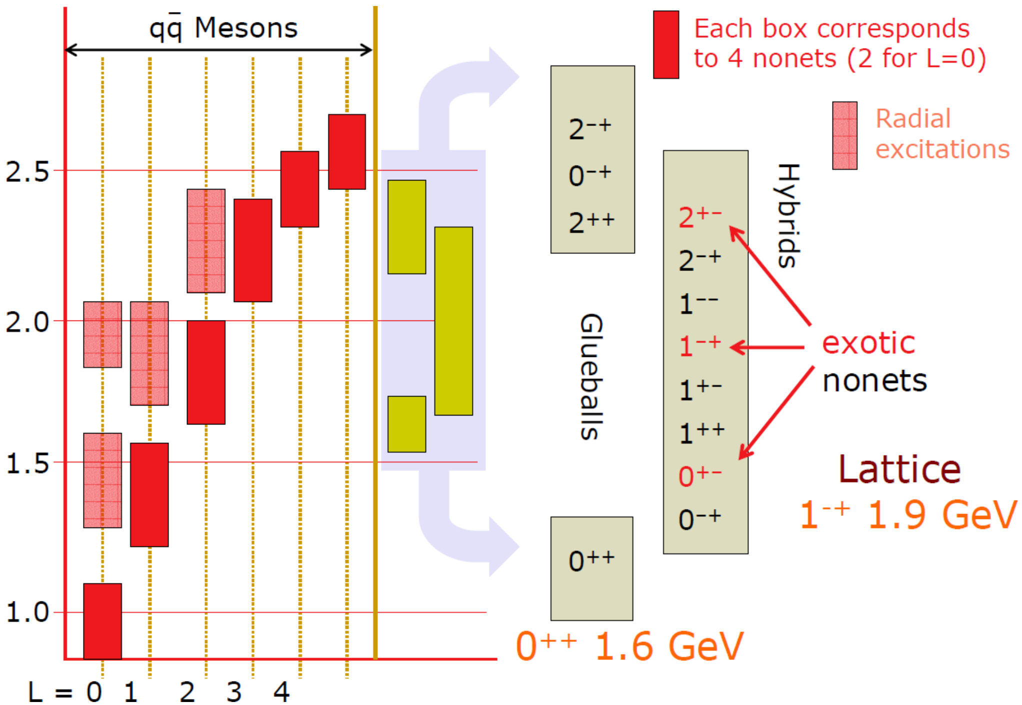
Models of hadron structure:
- Constituent Quark Model
- Lattice QCD
- Bag Model
- Flux tube model
- Sum rules approach

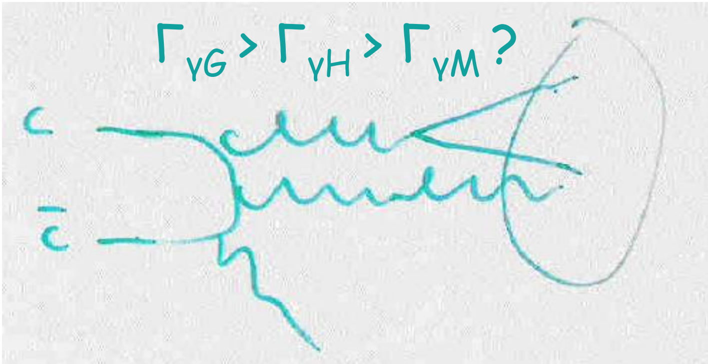
predict new forms of hadronic matter with the **glue degree of freedom** manifest explicitly:
- **Hybrids:**
- **Glueballs:**



One of the most important tasks of BES3

BES provides some ideal hunting grounds





"gluon-rich"

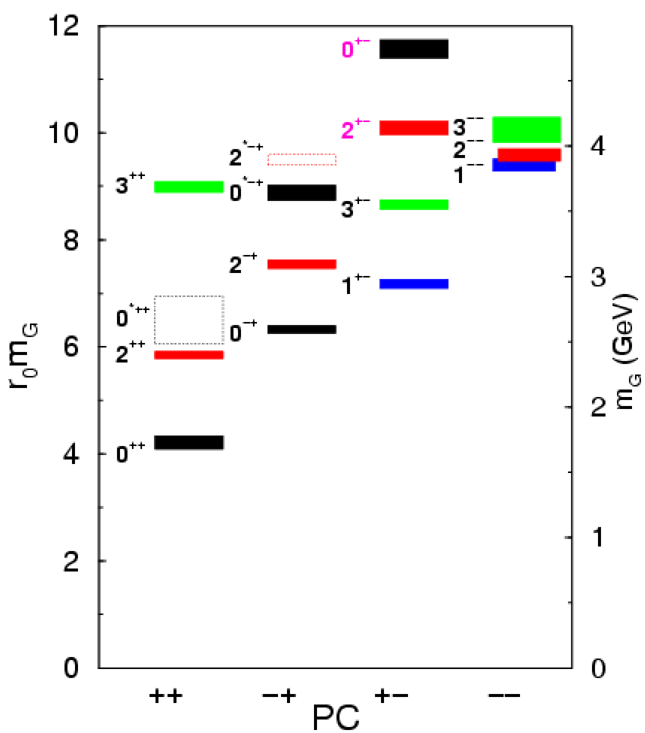
x

Power of high statistics

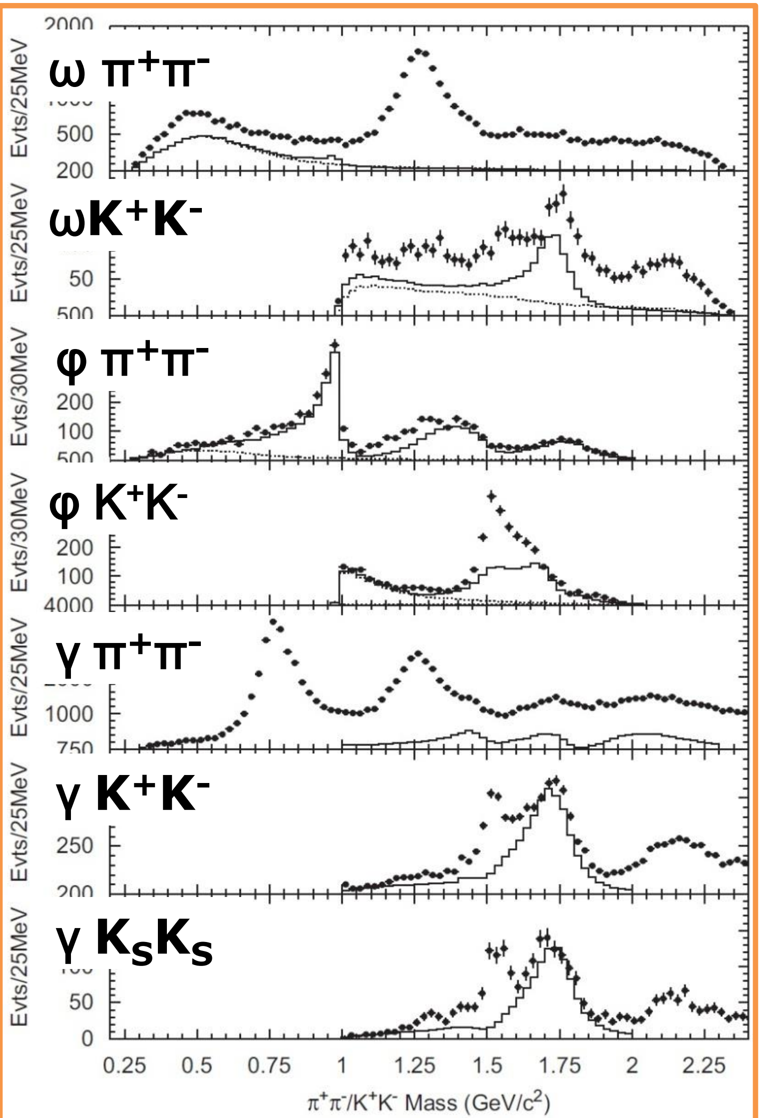
What we could have done with 1B-10B J/psi (psi', eta_c, chi_c)

Light glueballs (0+,0-,2+): ordinary J^PC

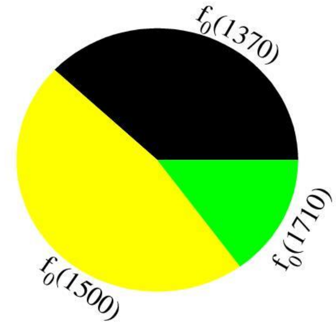
- Production mechanism: Gluon-rich process
- Flavor-blind decay patterns
- Overpopulation
- Solve mixing scheme



0++



@BES2

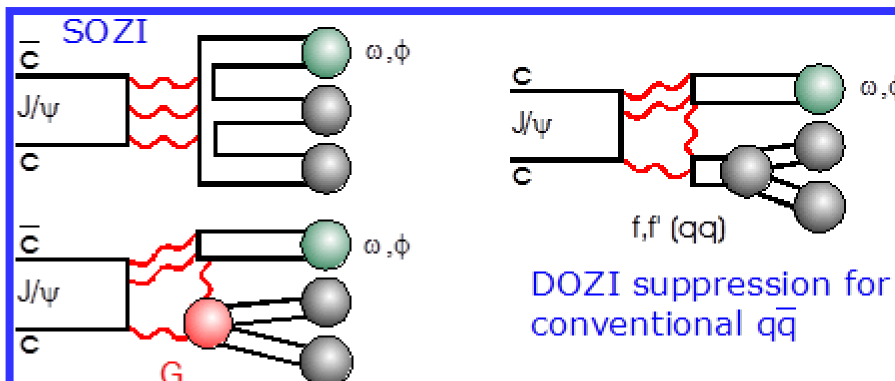


Glueball spread over 3 mesons

+ η(')η(') …

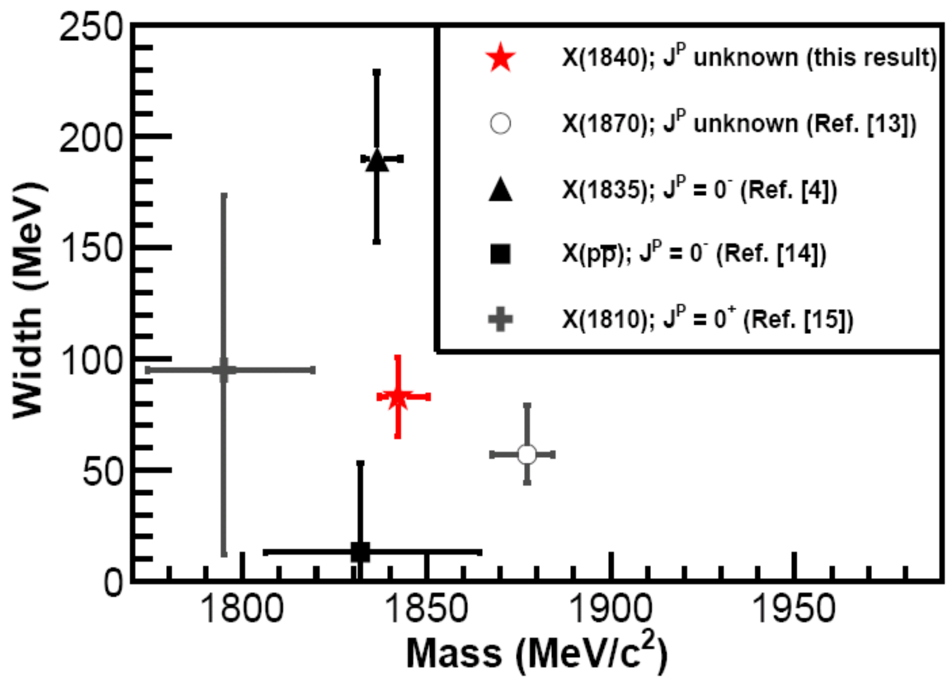
x 20(0)

DOZI enhanced?



0-+

eta(1295)
eta(1405/1475)

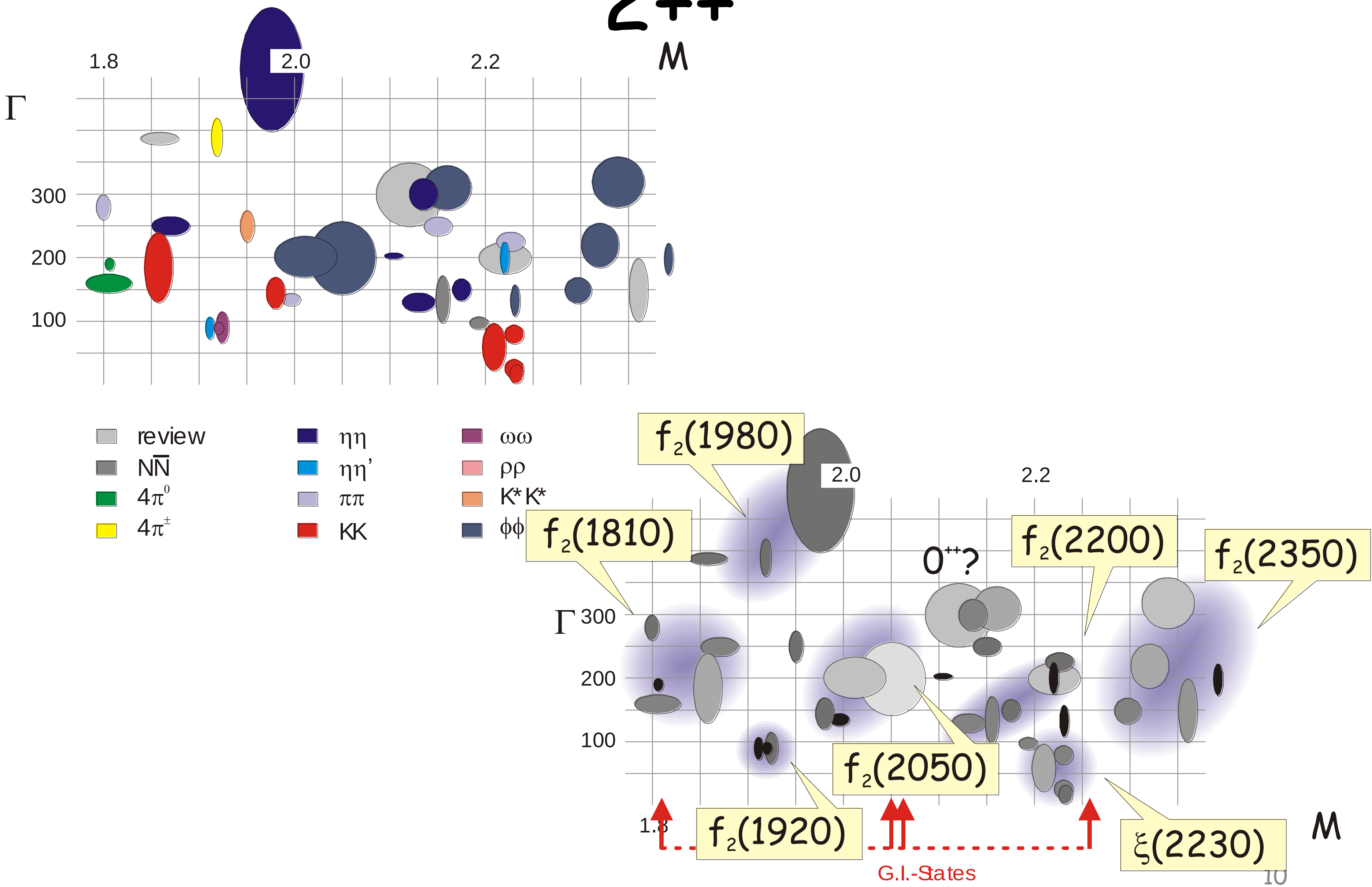


X(21xx/23xx): J^P unknown,
eta(2225),
...

Observations at BESIII with 225M J/ψ decays:

- ★ J/ψ→γ (3(π π)) X(1840) arXiV:1305.5333
- ○ J/ψ→ ω (ηππ) X(1870) PRL107, 182001
- ▲ J/ψ→γ (η'ππ) X(1835) PRL106, 072002
- ■ J/ψ→γ (ppbar) X(ppbar) PRL108,112003
- + J/ψ→γ (ωϕ) X(1810) PRD 87, 032008

2^{++}

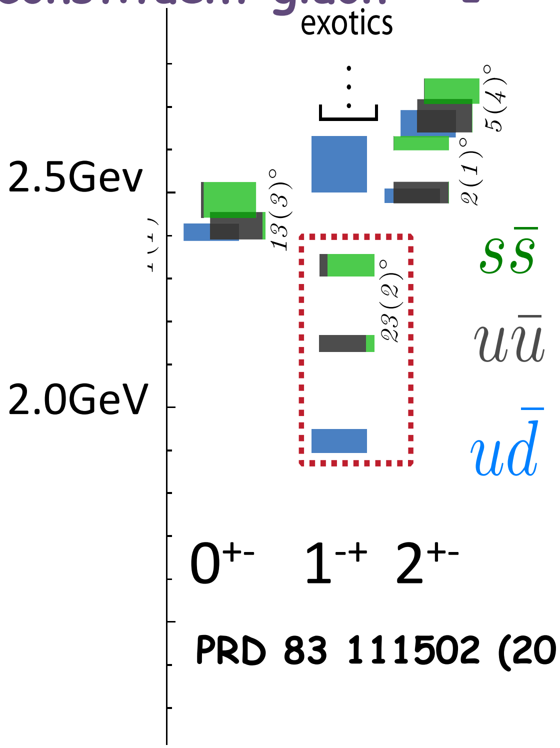


M
1.8
2.0
2.2
Γ
300
200
100
review
$N\bar{N}$
$4\pi^0$
$4\pi^\pm$
$\eta\eta$
$\eta\eta'$
$\pi\pi$
KK
$\omega\omega$
$\rho\rho$
K* K*
$\phi\phi$
$f_2(1980)$
$f_2(1810)$
0^{++}?
$f_2(2200)$
$f_2(2350)$
$f_2(2050)$
$f_2(1920)$
$\xi(2230)$
M
G.I.-States

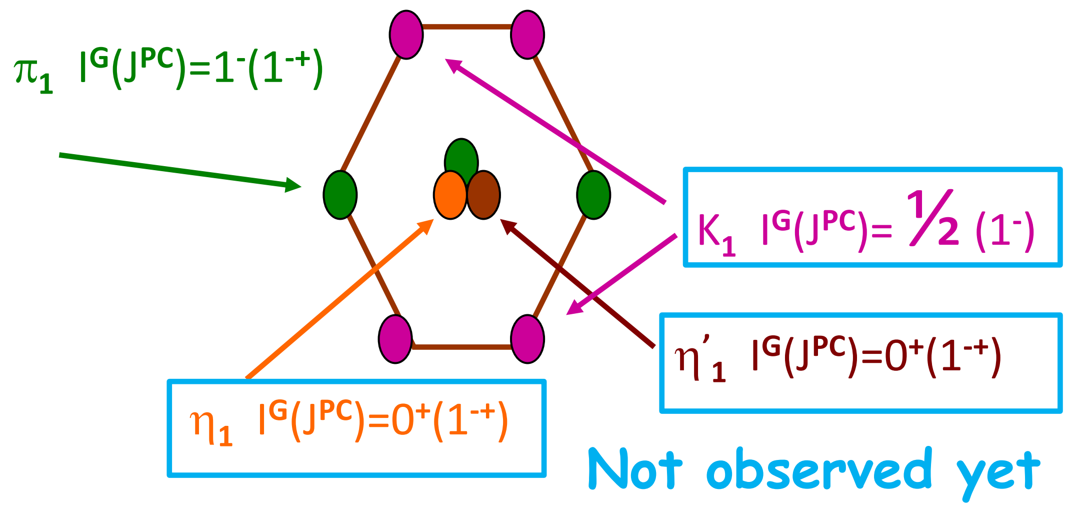
What we could have done with 1B-10B J/psi (psi', eta_c, chi_c)

Light hybrids: search for nonets

Lattice QCD Predictions: "constituent gluon"~ 1+-



PRD 83 111502 (2011)



	Approximate Mass (MeV)	J^{PC}	Total Width (MeV) PSS	IKP	Relevant Decays	Final States
π_1	1900	1^{-+}	$80-170$	120	$b_1\pi^\dagger$, $\rho\pi^\dagger$, $f_1\pi^\dagger$, $a_1\eta$, $\eta'\pi^\dagger$	$\omega\pi\pi^\dagger$, $3\pi^\dagger$, 5π, $\eta 3\pi^\dagger$, $\eta'\pi^\dagger$
η_1	2100	1^{-+}	$60-160$	110	$a_1\pi$, $f_1\eta^\dagger$, $\pi(1300)\pi$	4π, $\eta 4\pi$, $\eta\eta\pi\pi^\dagger$
η'_1	2300	1^{-+}	$100-220$	170	$K_1(1400)K^\dagger$, $K_1(1270)K^\dagger$, $K^*K^\dagger$	$KK\pi\pi^\dagger$, $KK\pi^\dagger$, $KK\omega^\dagger$
b_0	2400	0^{+-}	$250-430$	670	$\pi(1300)\pi$, $h_1\pi$	4π
h_0	2400	0^{+-}	$60-260$	90	$b_1\pi^\dagger$, $h_1\eta$, $K(1460)K$	$\omega\pi\pi^\dagger$, $\eta 3\pi$, $KK\pi\pi$
h'_0	2500	0^{+-}	$260-490$	430	$K(1460)K$, $K_1(1270)K^\dagger$, $h_1\eta$	$KK\pi\pi^\dagger$, $\eta 3\pi$
b_2	2500	2^{+-}	10	250	$a_2\pi^\dagger$, $a_1\pi$, $h_1\pi$	4π, $\eta\pi\pi^\dagger$
h_2	2500	2^{+-}	10	170	$b_1\pi^\dagger$, $\rho\pi^\dagger$	$\omega\pi\pi^\dagger$, $3\pi^\dagger$
h'_2	2600	2^{+-}	$10-20$	80	$K_1(1400)K^\dagger$, $K_1(1270)K^\dagger$, $K_2^*K^\dagger$	$KK\pi\pi^\dagger$, $KK\pi^\dagger$

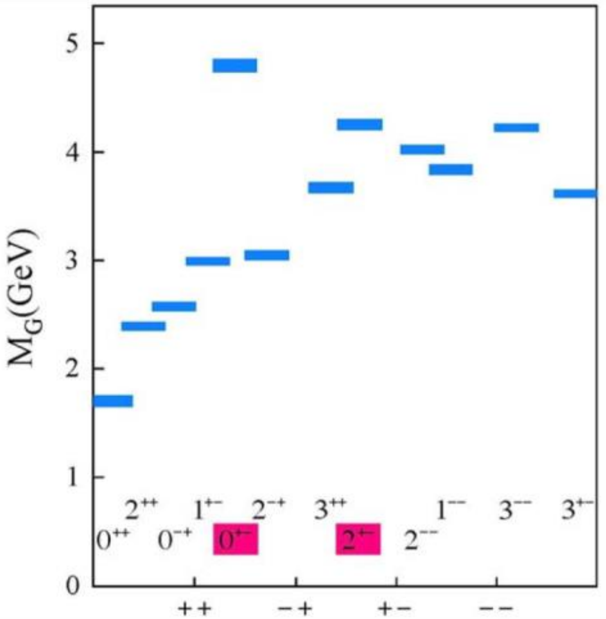
Phys.Rev. D59 (1999) 034016,
Phys.Rev. C82 (2010) 025208,
Phys.Rev. D83 (2011) 014006, …

What can be done with 10^12 J/psi ?

- **PWA is the key tool**
  - Computing is NOT an issue
  - Ambiguity from small component (THE main source of sys.err) will be reduced
  - Finer models are required to fit the data (THE main trouble for hadron spectroscopy)
- **The real question: any golden channels remained in post-BES3 era because of "10 B is not enough"???**
  - Glueballs
    - Br of J/psi radiative decays into benchmark channels are large enough
  - Hybrids
    - E.g. Br(chi_c1->pi1(1600)pi->eta'pi+pi-)~10^-4
  - **"Picky" mode for low BG**
    - E.g. J/psi-> gamma K_S K_S eta, J/psi->gamma eta' pi0 pi0

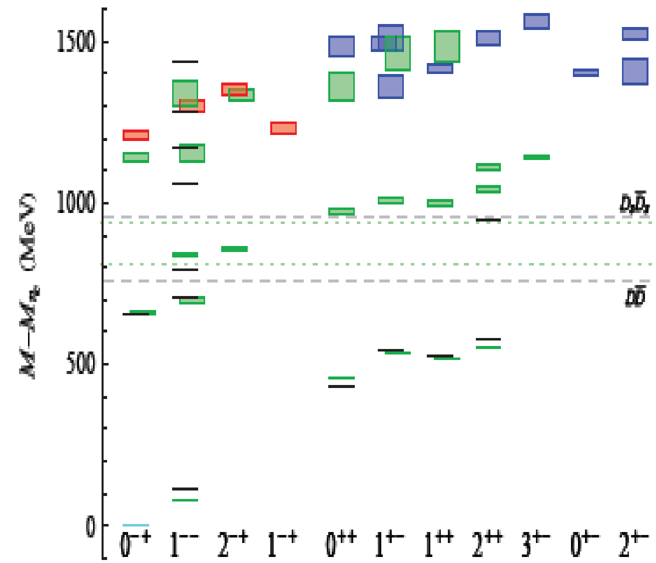
QCD exotics (more)

- **Heavy glueball**
  - “cleaner” environment, the meson states are much less numerous than in the light-quark sector and seem to be rather narrow→ reduced mixing
  - 2 exotic glueballs (AKA “oddballs”)
    - m(0+-) = 4140(50)(200) MeV
    - m(2+-) = 4740(70)(230) MeV
  - Low production rate (VS PANDA)



QCD exotics (more)

- **Transition of psi_g(hybrid) to 0-+, 1-+, 2-+**
  - Signature decay patterns
  - Unknown transition rate
  - input from China LQCD group?



- Decay of psi_g-> light hadrons offers the interesting possibility to produce light exotic meson

- Condition for DCPV: $|\bar{A}/A| \neq 1$
- Need $\bar{A}$ and A to consist of (at least) two parts
  - with different weak (φ) and strong (δ) phases
- Often realised by "tree" and "penguin" diagrams

$$A = |T| e^{i(\delta_T - \phi_T)} + |P| e^{i(\delta_P - \phi_P)} \qquad \bar{A} = |T| e^{i(\delta_T + \phi_T)} + |P| e^{i(\delta_P + \phi_P)}$$

$$A_{CP} = \frac{|\bar{A}|^2 - |A|^2}{|\bar{A}|^2 + |A|^2} = \frac{2|T||P| \sin(\delta_T - \delta_P) \sin(\phi_T - \phi_P)}{|T|^2 + |P|^2 + 2|T||P| \cos(\delta_T - \delta_P) \cos(\phi_T - \phi_P)}$$

Multibody hadronic decays may provide a good lab to search for new sources of CPV

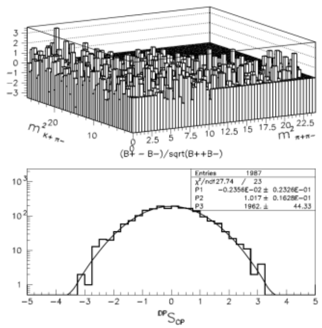
Problem with two-body decays:
- 2 observables (B, A_{CP})
- 4 unknowns ($|T|$, $|P|$, $\delta_T - \delta_P$, $\varphi_T - \varphi_P$)

- More observables (B & A_{CP} at each Dalitz plot point)
- Using isobar formalism, can express total amplitude as coherent sum of quasi-two-body contributions

$$A(m_{12}^2, m_{23}^2) = \sum_r c_r F_r(m_{12}^2, m_{23}^2)$$

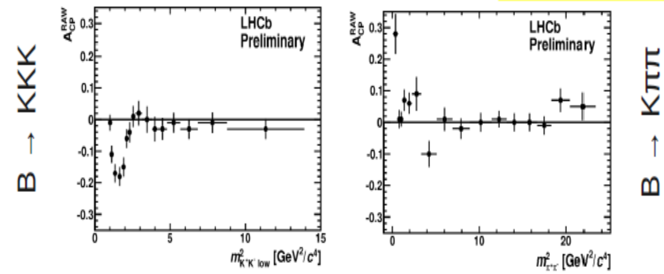
  - where c_r & F_r contain the weak and strong physics, respectively
  - n.b. each c_r is itself a sum of contributions from tree, penguin, etc.
- Interference provides additional sensitivity to CP violation

Hadron spectroscopy in charm Dalitz plot analysis



- Direct Dalitz plot analysis
  - Model independent (e.g. two-sample chi^2 tests, anisotropy ("Miranda"method), etc.)

LHCb-CONF-2012-018



Large CP violation effects with strong variation across the Dalitz plot
Detailed studies will be necessary to understand origin of these effects

- Dalitz plot analysis with hadronic input
  - increases sensitivity: differential observables
  - allows one to connect various reactions
  - necessary for quantitative extraction of weak phases
  - model dependence

Phys. Rev. D 78, 012004 (2008) [13 pages]

Evidence for direct *CP* violation from Dalitz-plot analysis of $B^{\pm}\to K^{\pm}\pi^{\mp}\pi^{\pm}$

$+44 \pm 10 \pm 4^{+5}_{-13}$ $\quad$ 3.7σ

Who is part of les Nabis

from theory:
I. Bigi, S. Gardner, C. Hanhart, B. Kubis, T. Mannel, U.-G. Meißner, J.R. Pelaez, M.R. Pennington

from experiment:
I. Bediaga, A.E. Bondar, A. Denig, T.J. Gershon, W. Grandl, B.T. Meadows, K. Peters, U. Wiedner, G. Wilkinson

The goals of les Nabis

to do all this ...

wrap-up

- **Strong amplitudes as inputs are crucial in Daltiz plot analysis (especially, direct CPV)**
- **Highly excited charmonium data sets, the program can be enriched** by the studies of heavy QCD exotics
- J/psi, psi' data sets,
  - BES3 physics programs: **if BES3 can accomplish its duty**, is there any "remained" golden channel?