

强子物理前沿研讨会

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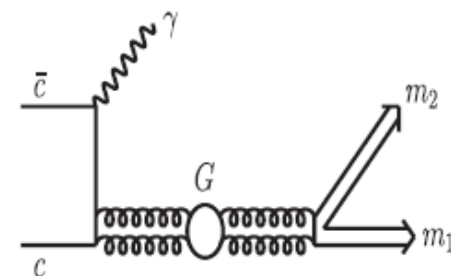
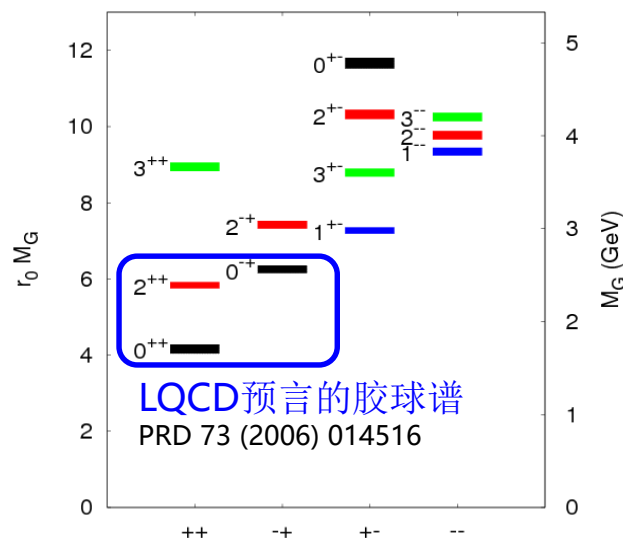


胶球的系统研究

- 胶球 $\rightarrow$ 体现胶子自由度的奇特量子态 $\rightarrow$ 胶子场 $\rightarrow$ 夸克禁闭
- 较轻的胶球具有常规量子数，与普通介子可能发生混合，无法直接区分
- 找到一个胶球
- 需要从多个产生/衰变过程，系统研究介子谱，寻找超出夸克模型的行为
- J/ψ 辐射衰变是丰胶子过程，理论预期胶球有较大产额



歪 ~ 我觉得我其实还可以抢救一下。



Systematic study of glueball at BESIII

Scalar : already " saturated "

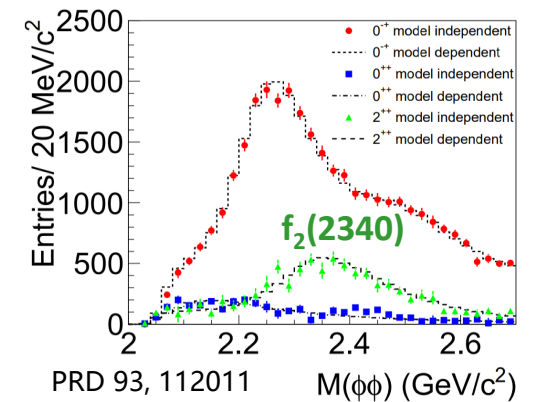
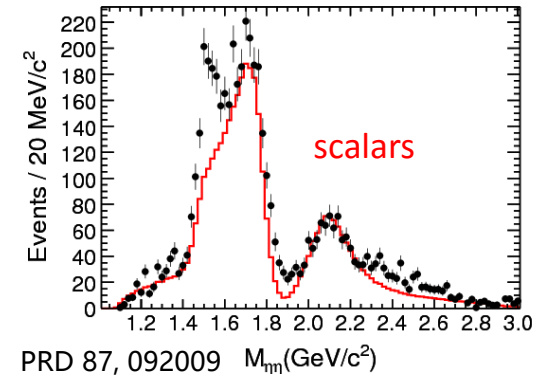
- LQCD : ground state 0^+ glueball ~ 1.7 GeV, first excitation ~ 2.1 GeV

✓ **Strong production of $f_0(1710)/f_0(2100)$ in $J/\psi \rightarrow \gamma \eta \eta / KK / \pi \pi$** , the pattern consists with LQCD' s prediction $\rightarrow$ largely overlap

Tensor : more complicated overpopulation

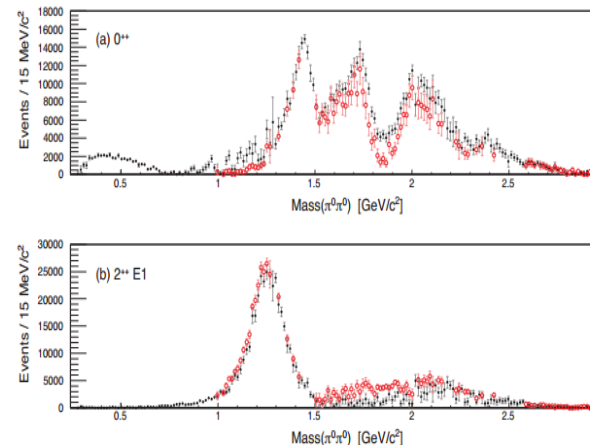
- LQCD : $2^{++}(2.3 \sim 2.4 \text{ GeV})$

✓ **Strong production of $f_2(2340)$ in $J/\psi \rightarrow \gamma \eta \eta / KK / \pi \pi / \phi \phi$** ; consists with LQCD' s prediction $\rightarrow$ largely overlap

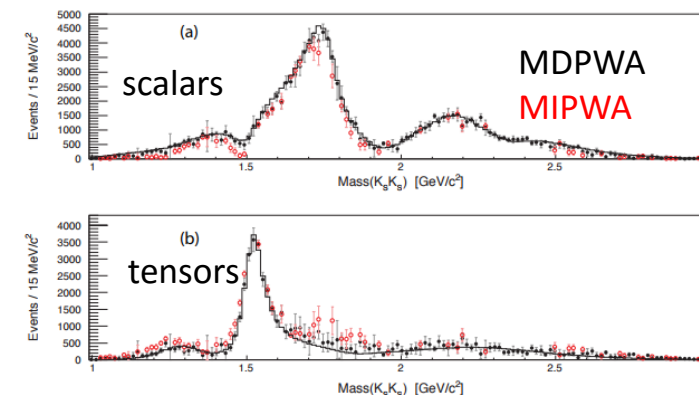


- $J/\psi \rightarrow \gamma \eta' \eta (')$ is a missing piece to the puzzle
 - A key to reveal the flavor structure of **$f_0(2100)$** and **$f_2(2340)$**
- $J/\psi \rightarrow \phi / \omega + PP$
- Coupled channel analysis
 - **assignment**

PRD 92, 052003



PRD 98, 072003



Systematic study of glueball at BESIII

Pseudoscalar : simple expected spectrum in quark model, **most promising, but very little known**

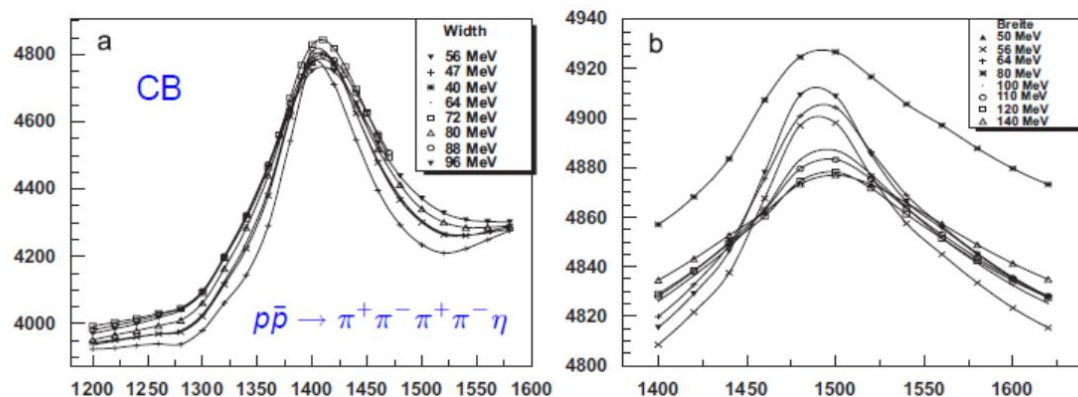
- LQCD : $0^{-+}(2.3\sim 2.6 \text{ GeV})$

✓ **Trajectory :**

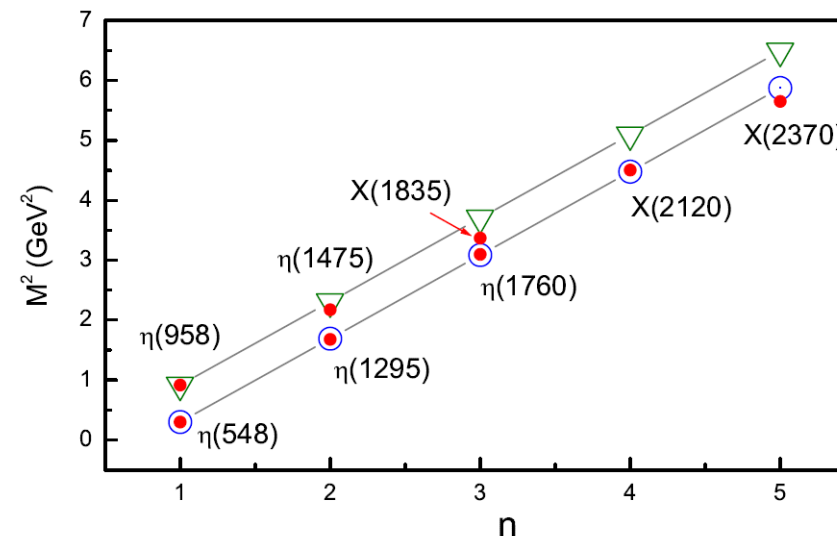
- $f_1(1285) ? \eta(1295) ?$
- $\eta(1405) ? \eta(1475) ?$
- $X(1835)/X(ppbar)$

- Flavor tags: $J/\psi \rightarrow \gamma\gamma V$, $J/\psi \rightarrow \phi/\omega X$

❑ **Above 2 GeV: X(2370)? ← High statistics needed**

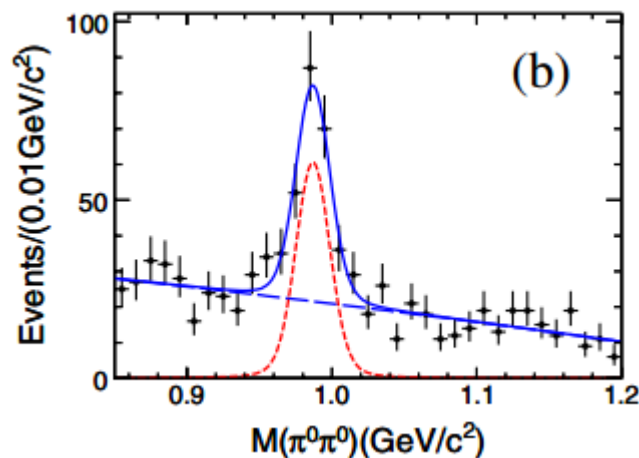
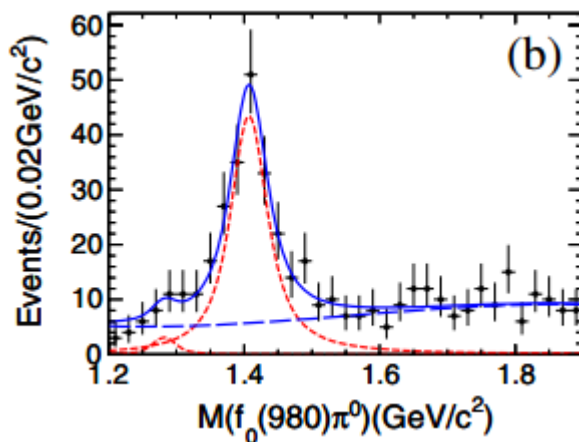


Long standing E-iota puzzle

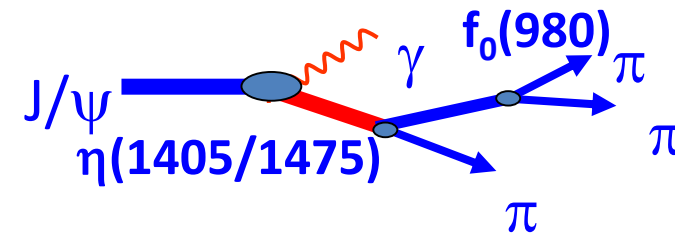


Where is the 0^{-+} glueball

Isospin-violating decay of $\eta(1405) \rightarrow f_0(980)\pi$

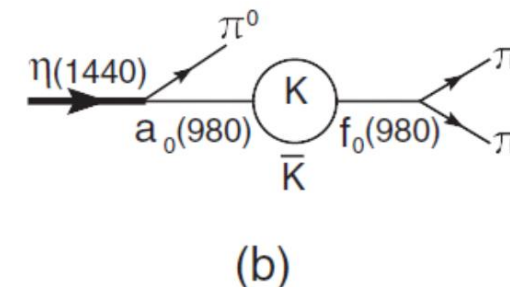
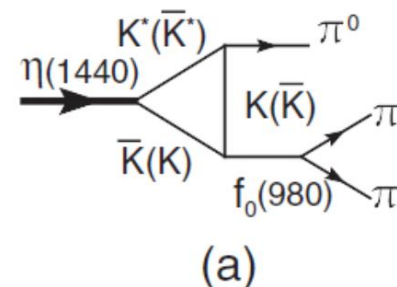


PRL 108 182001



$f_0(980)$ is extremely narrow: $\Gamma \cong 10 \text{ MeV}$.

PDG: $\Gamma(f_0(980)) \cong 40 \sim 100 \text{ MeV}$.



Anomalously large isospin violation:

$$\frac{Br(\eta(1405) \rightarrow f_0(980)\pi^0 \rightarrow \pi^+\pi^-\pi^0)}{Br(\eta(1405) \rightarrow a_0^0(980)\pi^0 \rightarrow \eta\pi^0\pi^0)} \cong (17.9 \pm 4.2)\%$$

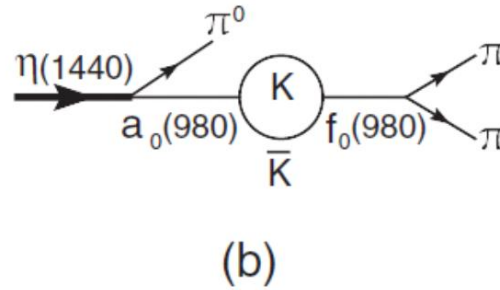
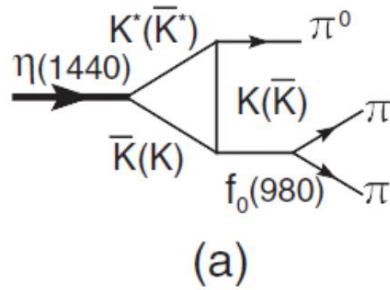
$$\xi_{af} = \frac{Br(\chi_{c1} \rightarrow f_0(980)\pi^0 \rightarrow \pi^+\pi^-\pi^0)}{Br(\chi_{c1} \rightarrow a_0(980)\pi^0 \rightarrow \eta\pi^0\pi^0)} < 1\% (90\% \text{ C.L.})$$

PRD, 83(2100)032003

Triangle singularity is proposed

Amplitude analysis of $f_1(1285), \eta(1405)$

Joint efforts of exp-th



Ongoing amplitude analyses

$$J/\psi \rightarrow \gamma \pi^0 \pi^0 \pi^0$$

$$J/\psi \rightarrow \gamma \eta \pi^0 \pi^0$$

$$J/\psi \rightarrow \gamma K_S K_S \pi^0$$

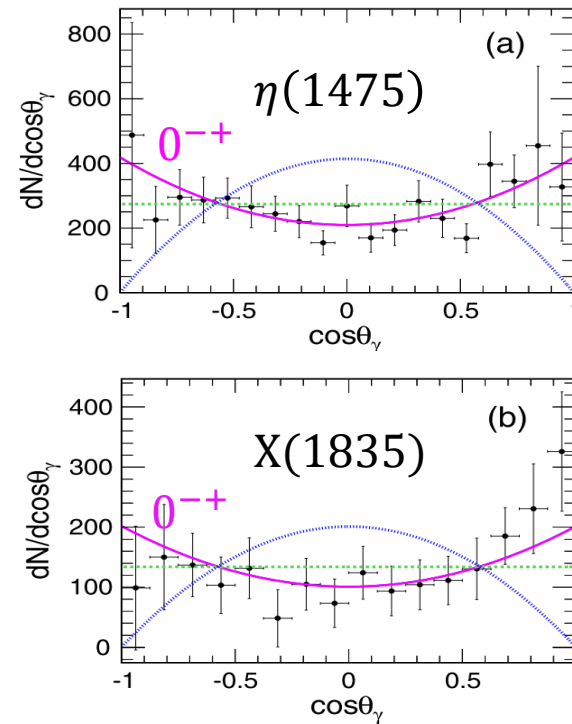
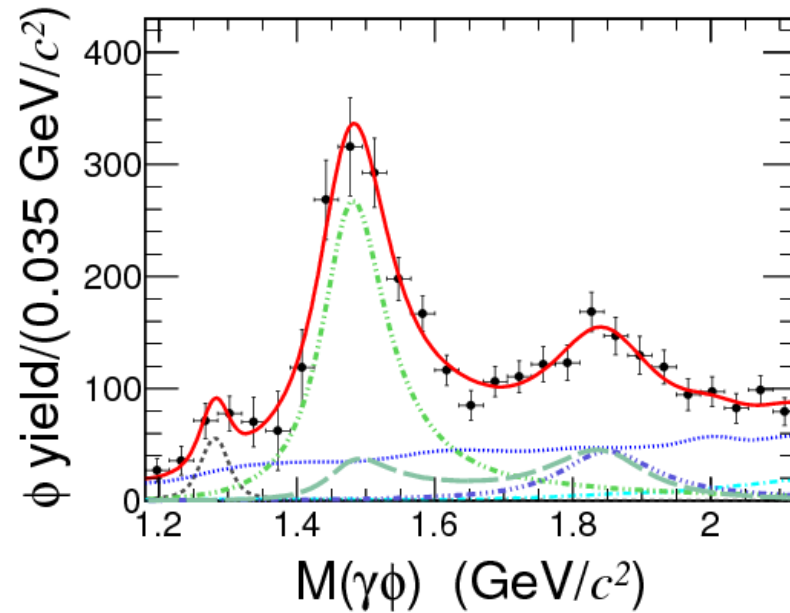
Original : $A_{total} = \epsilon_{\psi_\mu} \epsilon_{\gamma_\nu} \Lambda U^{\mu\nu}$

Modified: $A_{total} = \epsilon_{\psi_\mu} \epsilon_{\gamma_\nu} (\Lambda U^{\mu\nu} + \Lambda' I U^{\mu\nu})$

coefficient to be fitted Loop integral of coupling

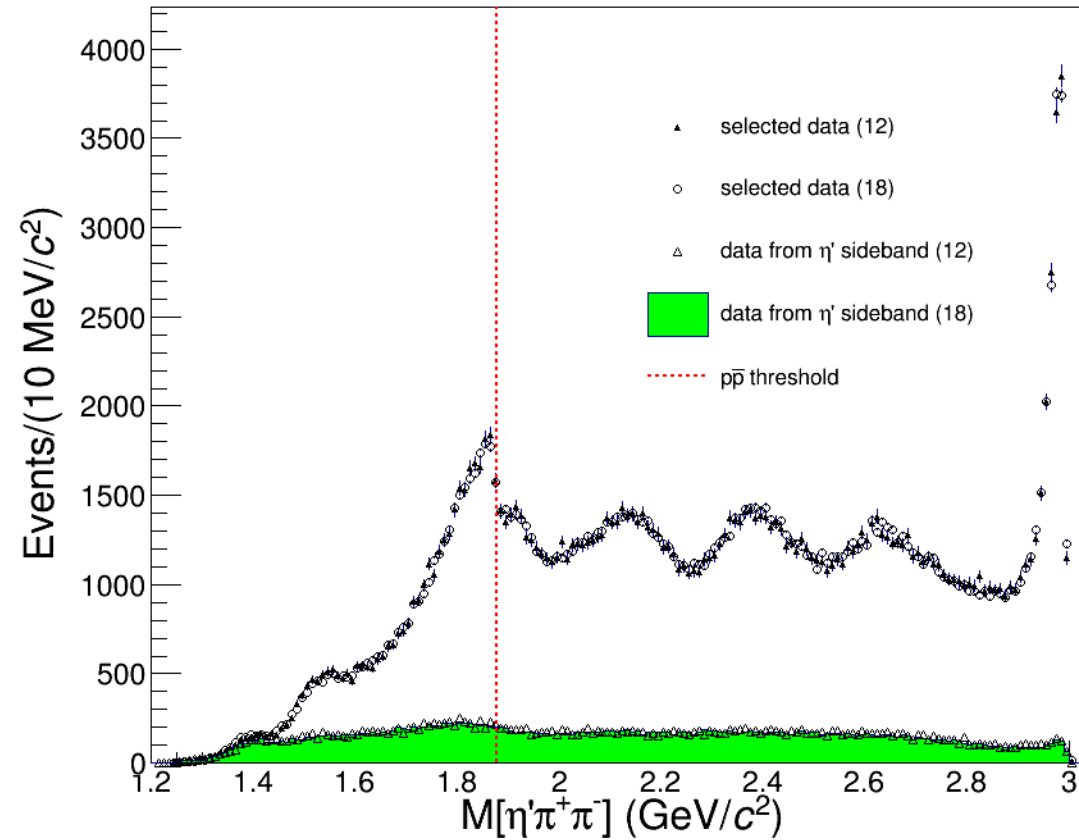
$\eta(1405)$ in J/ψ double radiative decays

- Critical information on the flavor structure
- PWA in the future



$X(2370)$: 0^{-+} glueball?

$$J/\psi \rightarrow \gamma \eta' \pi \pi$$



Searching for $X(2370)$ in more decay modes is a critical test for glueball

Glueball program at BESIII in a nutshell

	0^+	2^+	0^-
$J/\psi \rightarrow \gamma PP$			
$J/\psi \rightarrow \gamma VV$			
$J/\psi \rightarrow \gamma PPP$			

To-do:

- $0^+, 2^+$: Coupled channel analyses
 - $J/\psi \rightarrow \gamma PP$
 - $J/\psi \rightarrow \omega/\phi + X$
- 0^- : trajectory, X(2370)
 - $J/\psi \rightarrow \gamma PPP$
 - $J/\psi \rightarrow \gamma\gamma V$

$J/\psi \rightarrow \gamma \eta \eta \quad / \eta' \eta' / \eta \eta' / \pi^0 \pi^0 / K_S K_S$

$J/\psi \rightarrow \gamma \omega \phi / \phi \phi / \omega \omega$

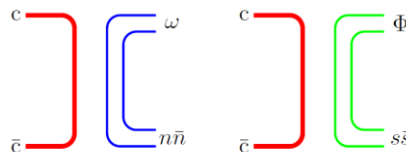
$J/\psi \rightarrow \gamma \eta' \pi \pi \quad / \eta' K K / \eta \pi \pi / K K \pi / \eta K K / \underline{\pi \pi \pi}$

- PWA published
- Published, PWA undone
- Ongoing

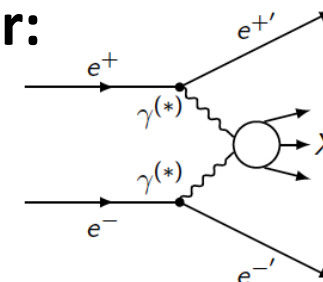
Flavor Filters:

$J/\psi \rightarrow \gamma X \rightarrow \gamma \gamma V$

$J/\psi \rightarrow \omega/\phi + X$

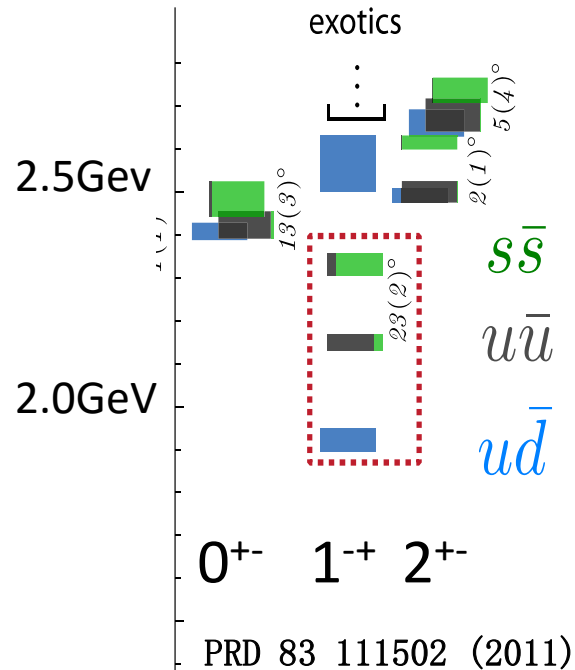


Anti filter:



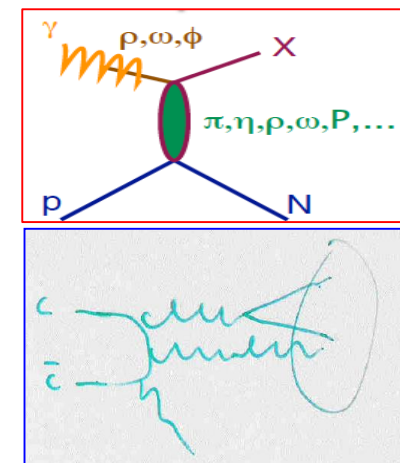
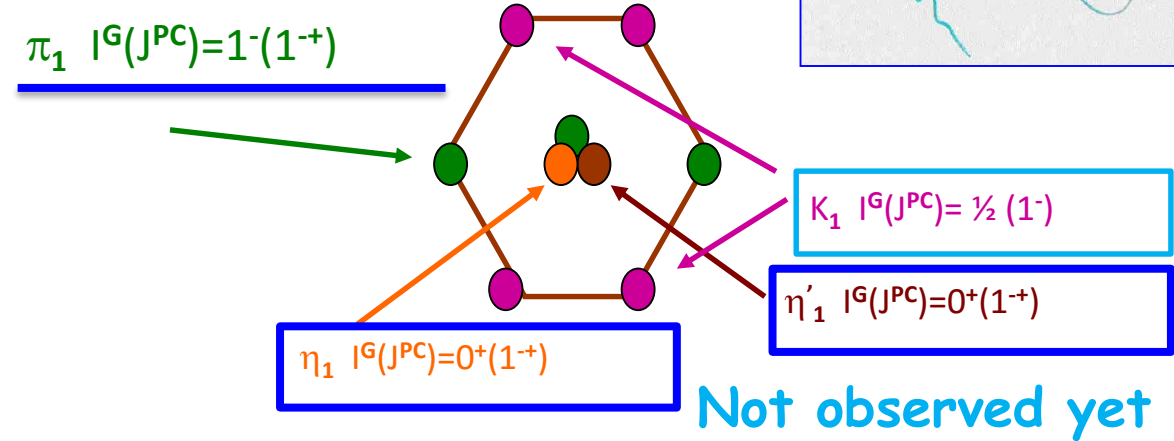
Hybrids

Lattice QCD Predictions:



- Nonet is important
- Isoscalar hybrids in J/ψ radiative decays (byproduct of amplitude analysis for glueball searches)

GlueX@JLab
BESIII



关于**BESIII** 振幅分析的若干问题

从实验角度来说

- 用一系列极大似然拟合做假设检验和参数估计
 - 模型（PDF）
 - 似然值
 - 拟合策略
 - 拟合正确性，拟合优度
 - 结果的诠释

实验的困难

实验对理论家的需求

模型选择：有哪些共振态

从N个可能的共振态里挑出M个数据里存在的成分：

- 一次拟合的计算量 $\propto N_{iteration} * N_{data} * N_{wave}^{2\sim3}$
 - ✓ 并行计算，例如GPUPWA
- 参数太多，收敛困难
 - ☹️
- 大量假设检验不可能都做，初值敏感，主观性
 - ✓ 机器学习（例如LASSO + CV）

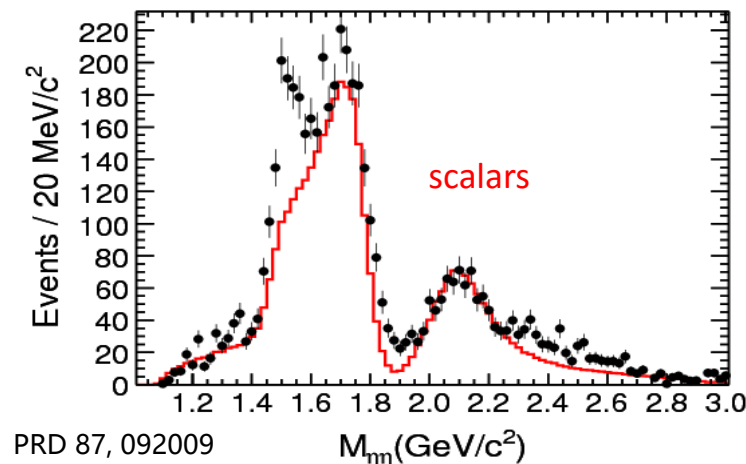
f0 的overpopulation,
胶球混合？



f0(1370)是否存在？
f0(1710) / f0(1790)/f0(1810)?
BES 的f0(1500) 比PDG值要低



如何确定有多少f0?
如何确定其参数？



- N个可能的共振态不确定
- 共振态参数不确定（PDG质量宽度误差）
- 共振态描述不确定（BW?）

加入更多共振态直至拟合变好 vs 拟合不好不一定是缺少共振态

动力学函数

- 如何描述共振态/非共振态

- BW

- 阈值效应、耦合道分析 ← 理论与实验深入合作

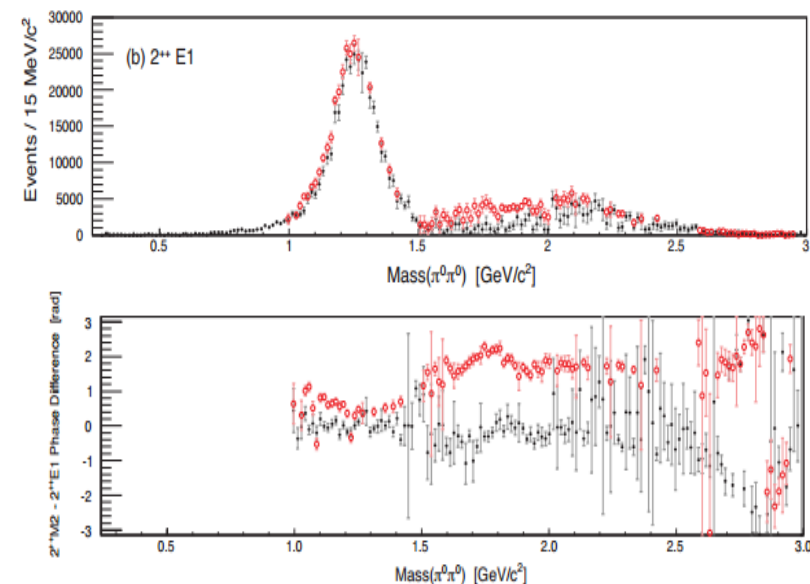
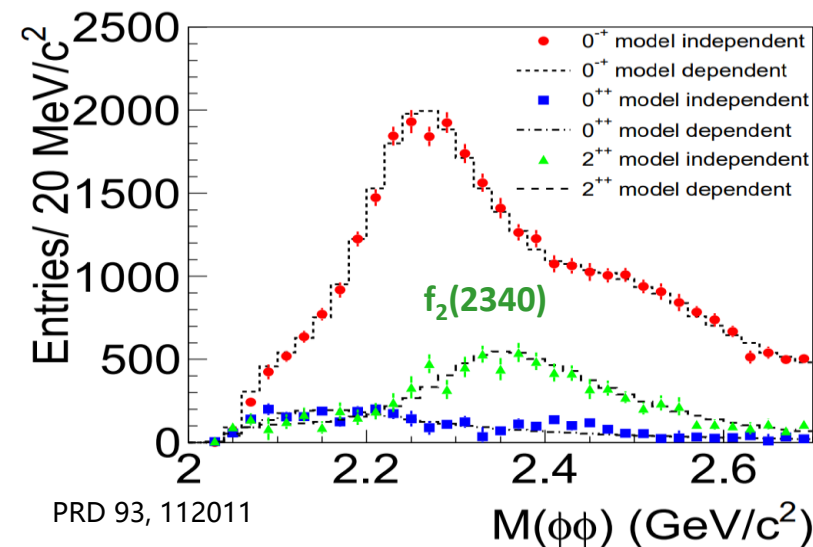
- 幺正性、解析性，哪些约束起主要作用
 - 实验上可用的动力学函数

- 可靠的共振态参数 ← 直方图不是实验目标

- 模型的系统误差：BW的pole和正确的pole差多少

- Quasi-model independent PWA, “Argand plot”

- 一些情况存在数学多解
 - 需要参考振幅并且其他成分已知
 - 需要大量事例
 - 从QMIPWA如何得到共振态信息



实验分辨

- 窄共振态和精细谱形需要考虑分辨
 - 能否用谱形区分不同动力学模型？ ← 能否通过谱形的细微差别得到pole在复平面的行为差别？
- BESIII, CLEO-c : 数值卷积（高斯采样）
- Other approach?

本底

- 本底（及其探测效率）
modeling困难→强子谱学主要使用本底减除
- ✓ 用低本底过程： $J/\psi \rightarrow \gamma K_S K_S$
- ✓ Multi-dimensional sidebands (Q-factor method)
- ✓ Multi-dimensional reweighting MC

