A Comprehensive Study of the Radiative Decay of J/ψ and ψ(2S) to Pseudoscalar Meson Pairs and Search for Glueballs

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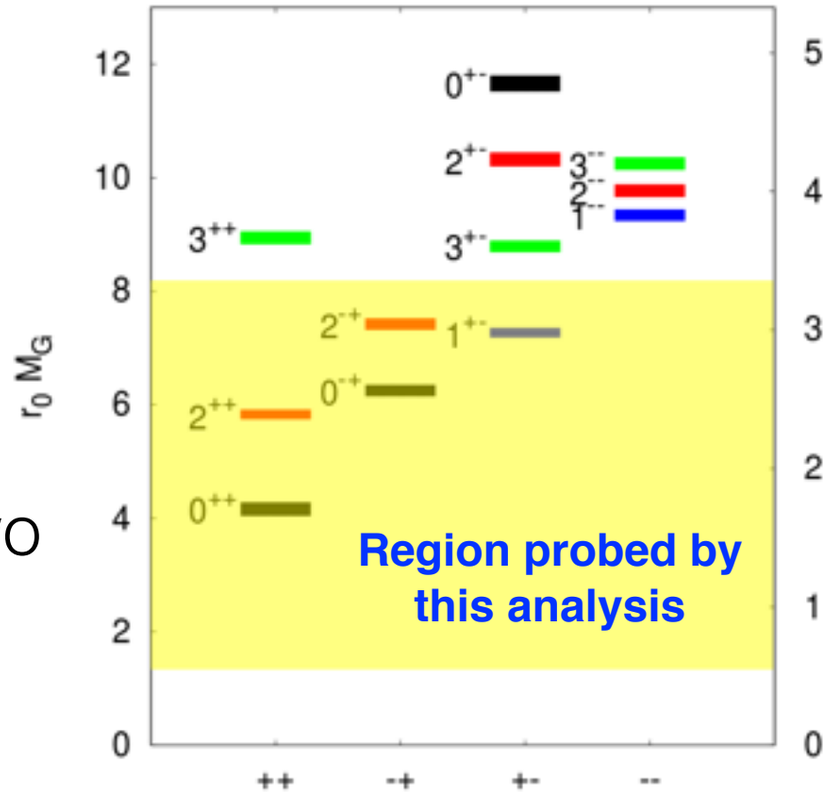
Introduction

- QCD predicts the existence of **glueballs**, *gg* and *ggg* bound states.
- Glue-rich radiative decays of heavy quarkonia, ψ,Υ → ɣ + *gg*, are expected to couple strongly to these states (C=+, J even).
- The lowest mass glueballs, $J^{PC} = 0^{++}, 2^{++}$, are naively expected to have decay patterns into two pseudoscalars based on flavor SU(3).
- However, the physical states we observe are mixtures of normal mesons and glueballs with the same quantum numbers.



Glueball spectrum from Chen et al.

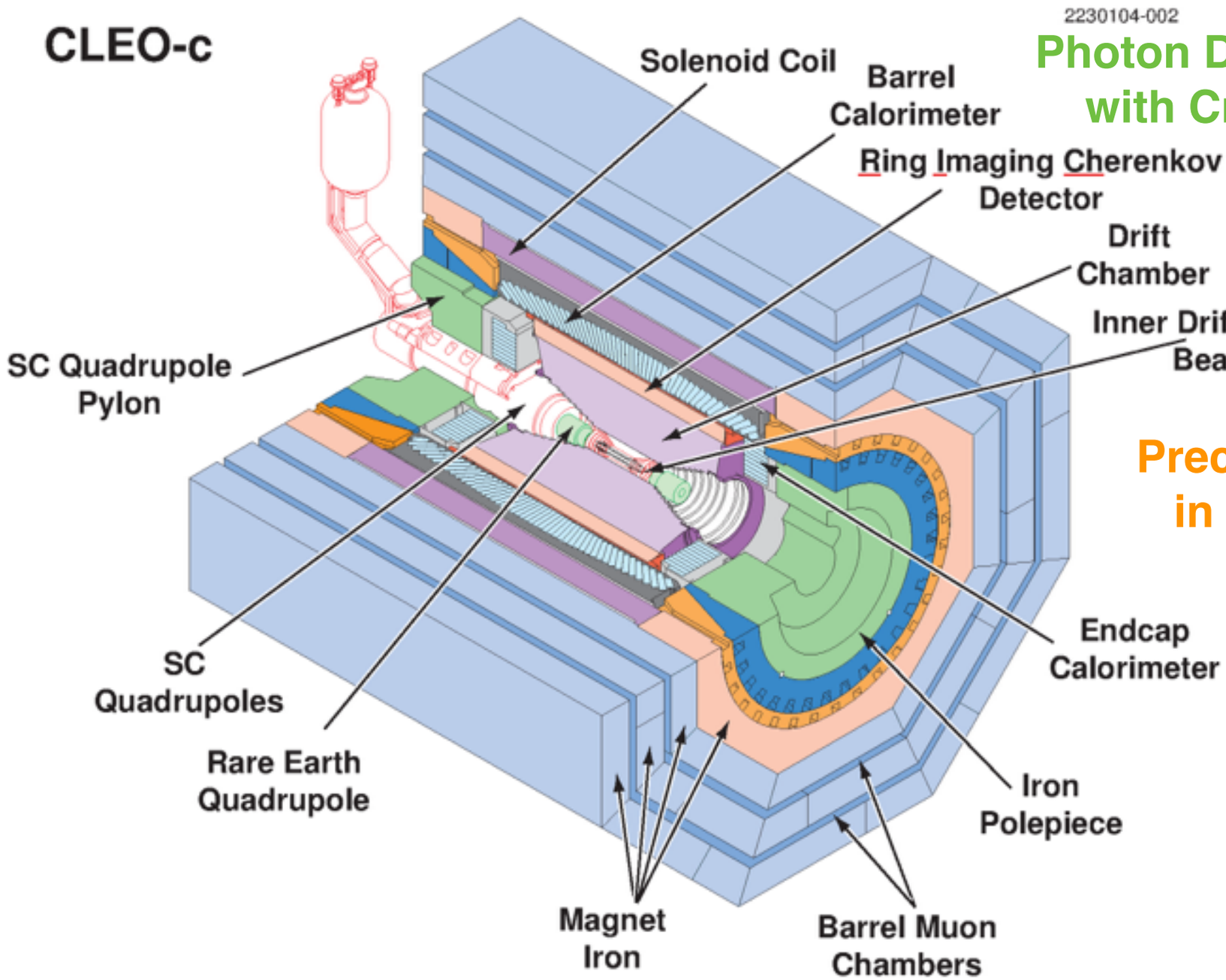
- To disentangle these contributions and understand the contribution of glueballs to the meson spectrum, we need to make comprehensive and systematic measurements of these different final states.
- We have done so in decays of J/ψ and ψ(2S).

Introduction

- We measure decays J/ψ, ψ(2S) → γ + [$\pi^+\pi^-$, $\pi^0\pi^0$, K^+K^-, K_SK_S, ηη] using e^+e^- annihilation data taken with the CLEO-c detector:
  - **25 M** directly produced ψ(2S)
  - **5 M** J/ψ produced via ψ(2S) → $\pi^+\pi^-$ J/ψ
    Tagging via $\pi^+\pi^-$ provides clean J/ψ sample.
- We fully reconstruct these decays and kinematically fit them.

- Previous J/ψ measurements by CB, Mark III, DM2, BES:
  - BES II, **58 M** J/ψ, decays to γ + [ππ, KK]
  - BES III, **228 M** J/ψ, decays to γ + ηη
- No previously published ψ(2S) results, results shown here are the **first**.
  - Unpublished BES II results from **14 M** ψ(2S)

CLEO-c Detector



Photon Detection with Crystal Calorimeter

π/K separation using RICH and DC dE/dx

Precision tracking in 1T B field

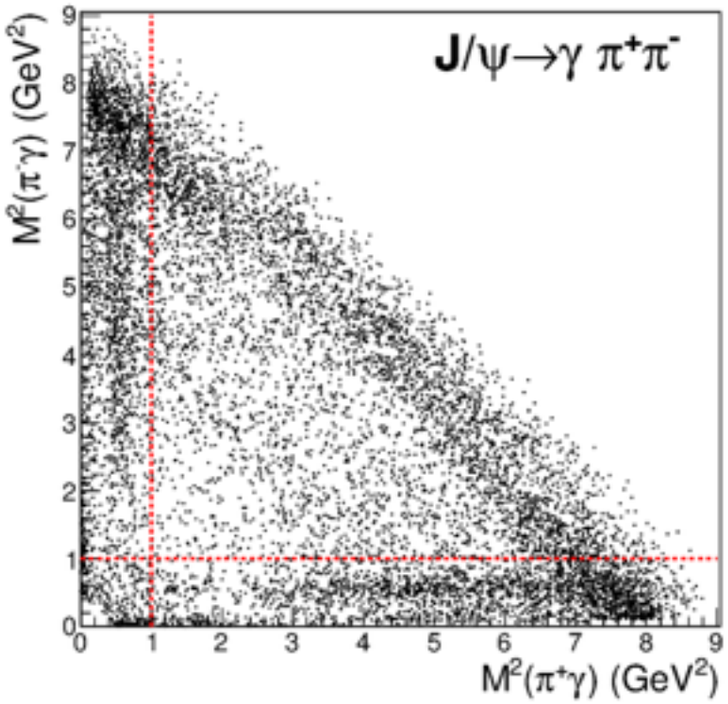
Acceptance:
$|\cos\theta| < 0.93$

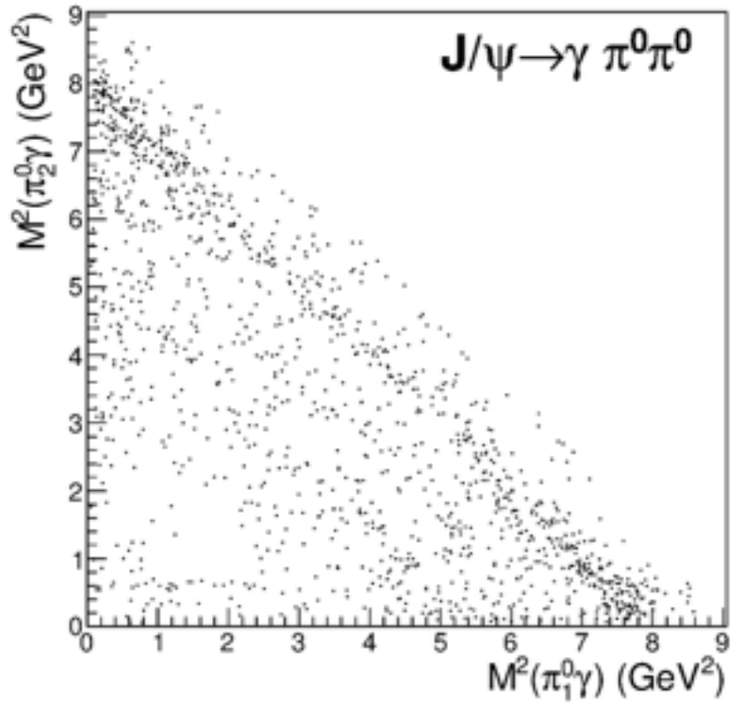
Charged particles:
$\sigma_p/p = 0.6\%$ @ 1 GeV/c

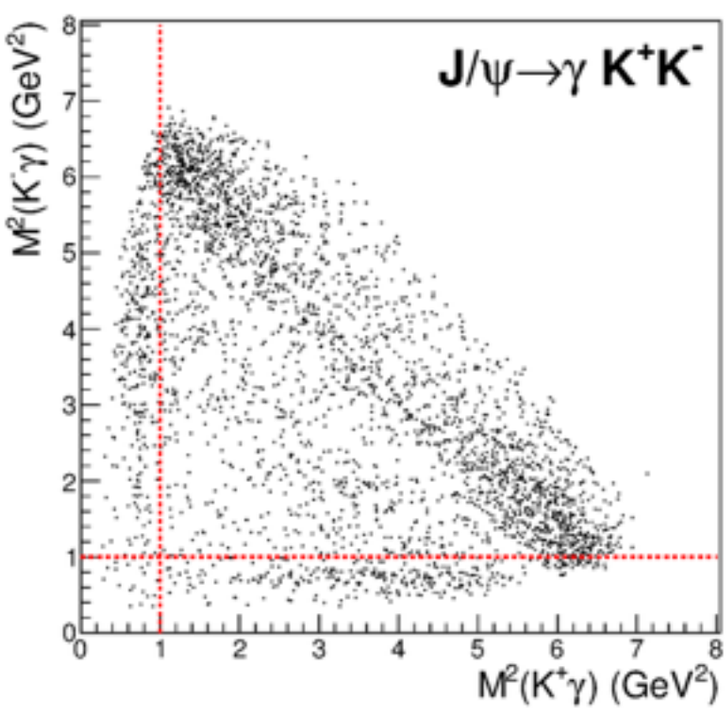
Photons:
$\sigma_E/E = 2.2\%$ @ 1 GeV
$\sigma_p/p = 5\%$ @ 100 MeV

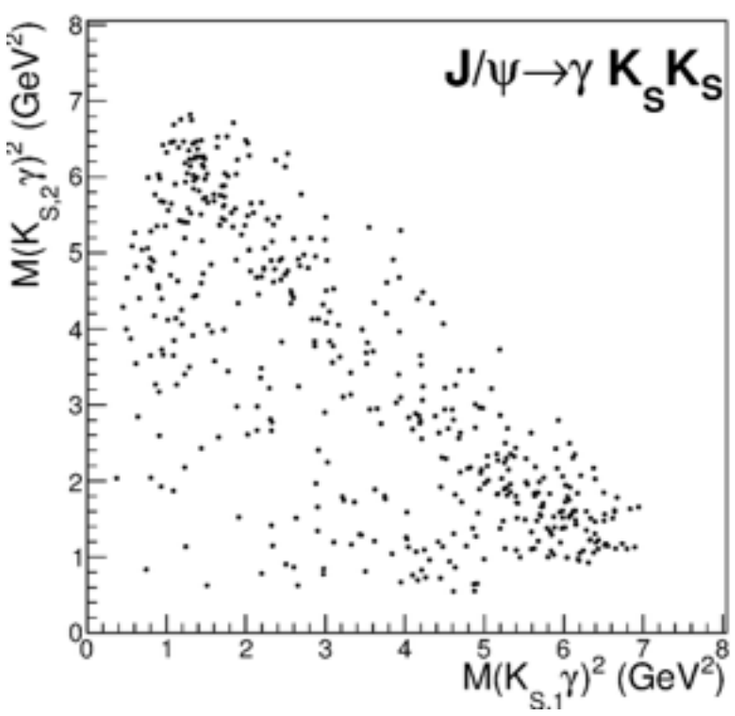
- Precision charged and neutral particle reconstruction and identification leads to clean mass spectra with small backgrounds.

Dalitz Plots in J/Ψ Decay



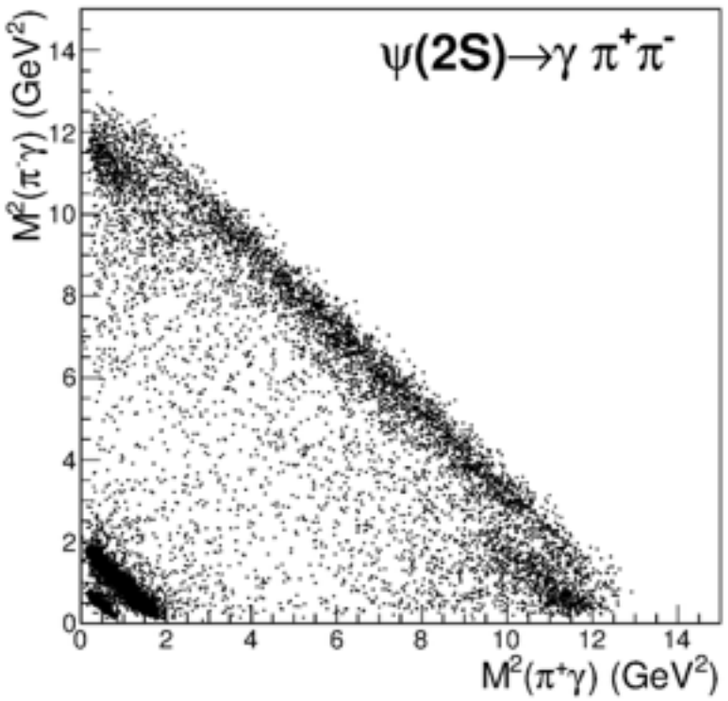


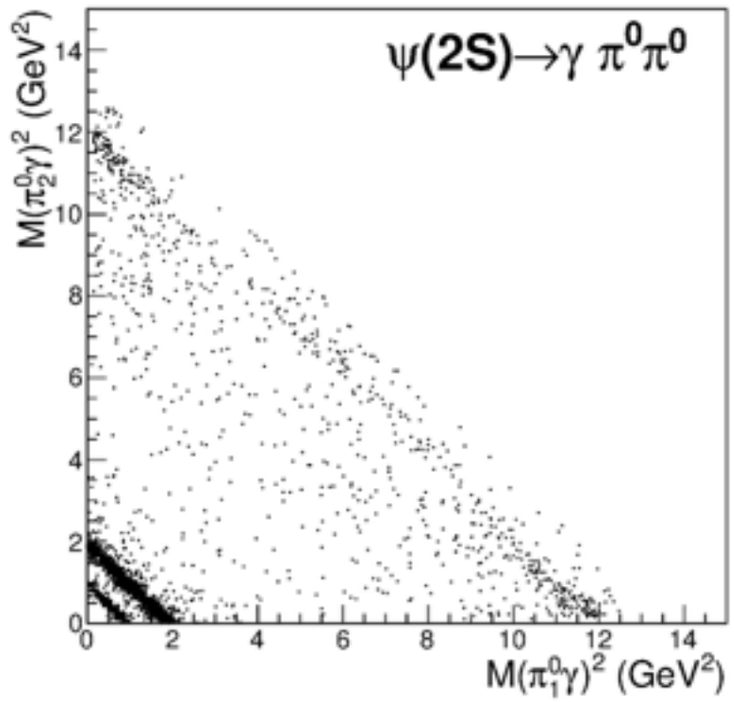


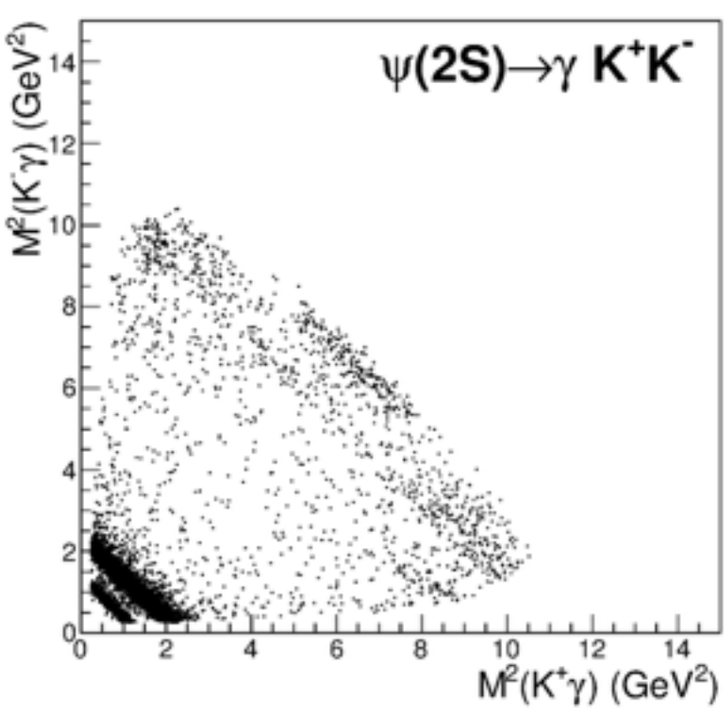


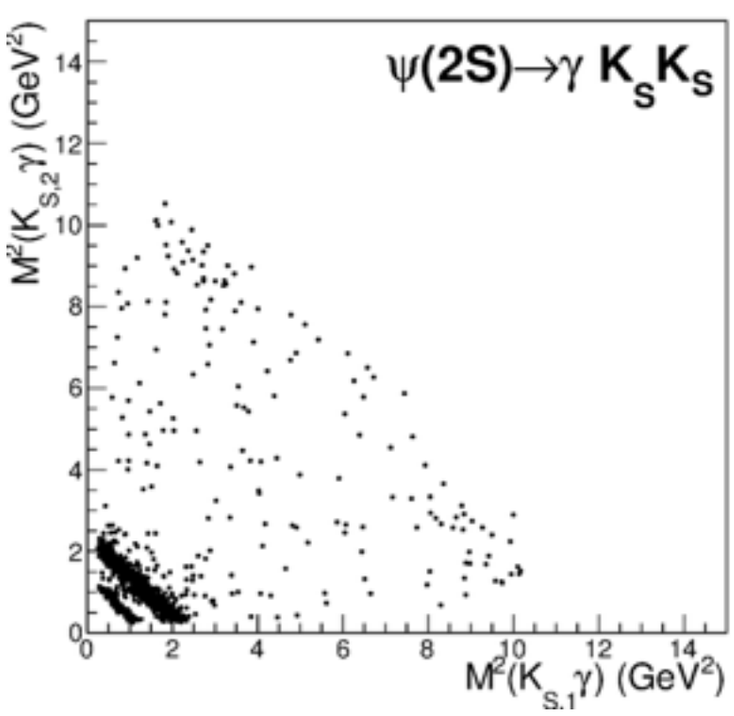
- Cut on $\pi^+\pi^-$ and K^+K^- Dalitz plots to reject $\rho\pi$ and KK^* decays.

Dalitz Plots in Ψ(2S) Decay



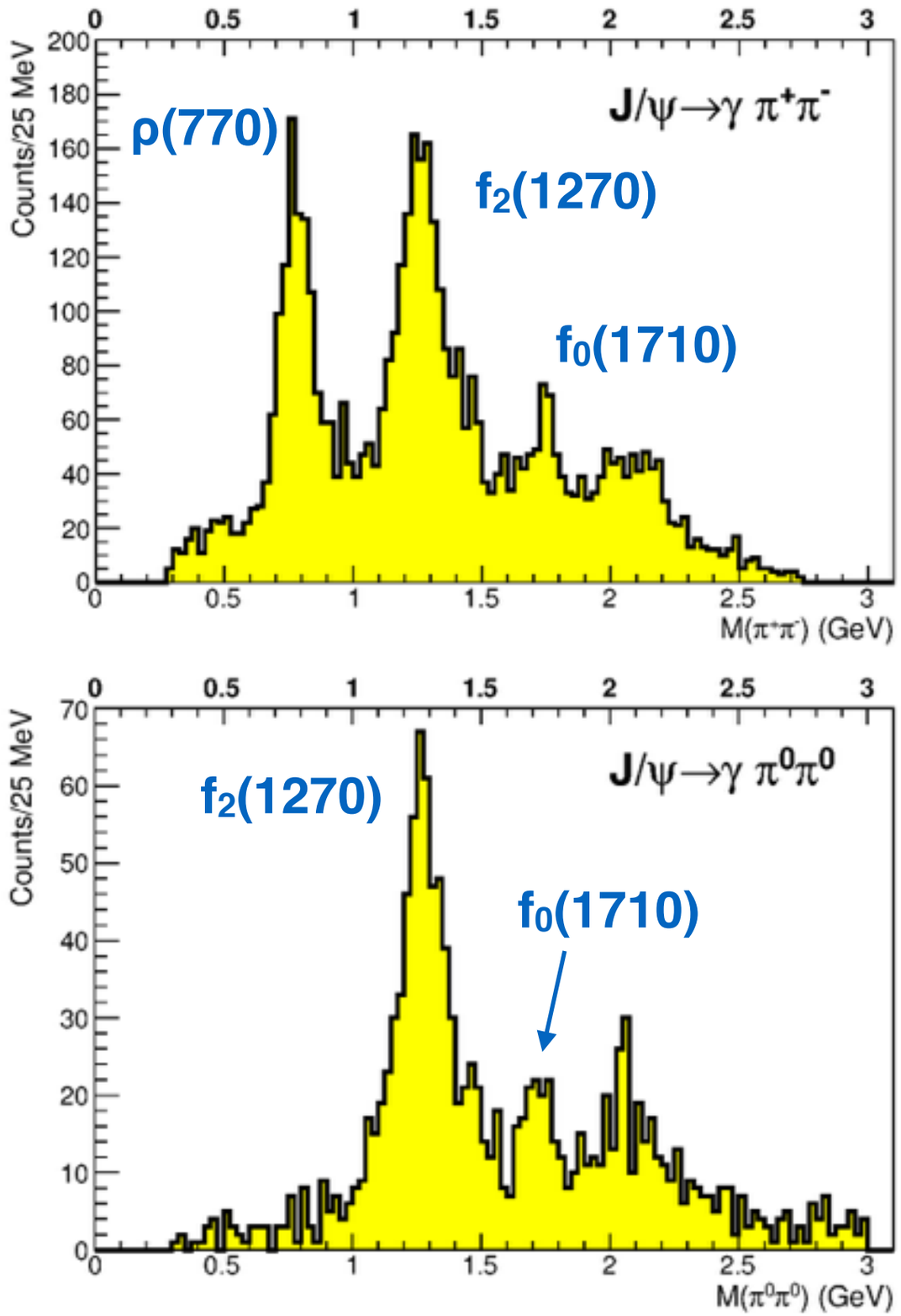


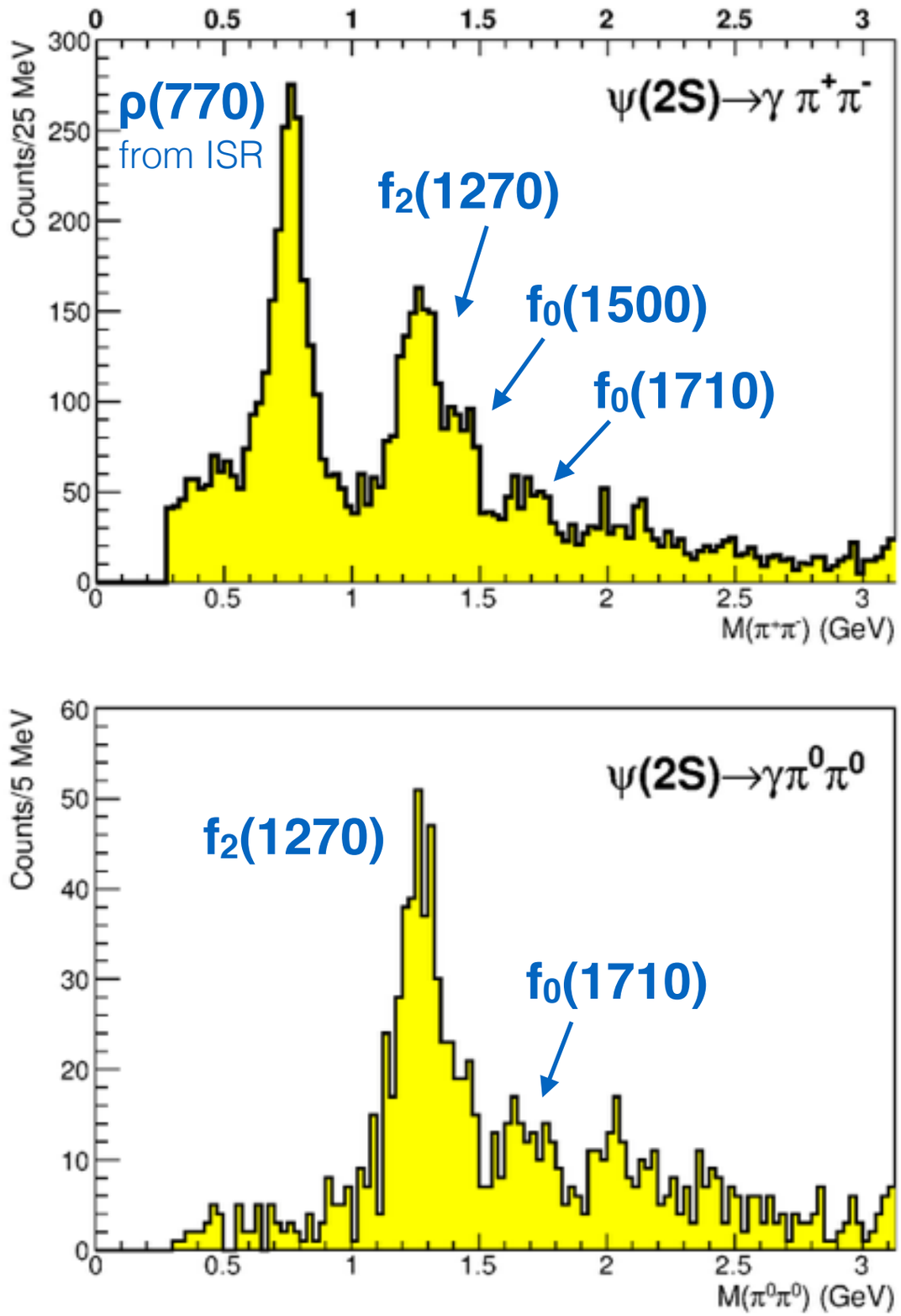




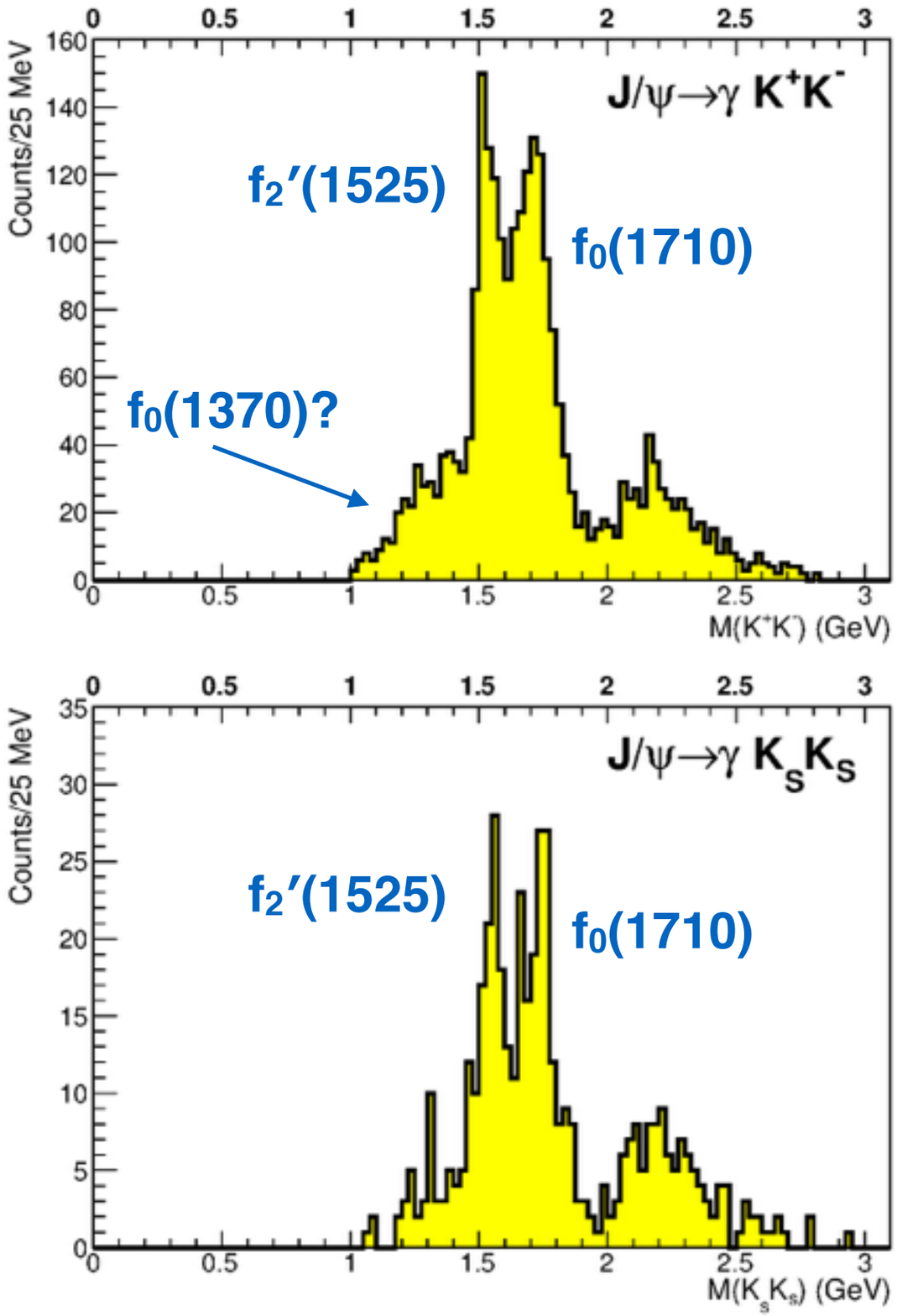
- Strong bands due to χ_{cJ} decays, $\rho\pi$ and KK* decays suppressed.

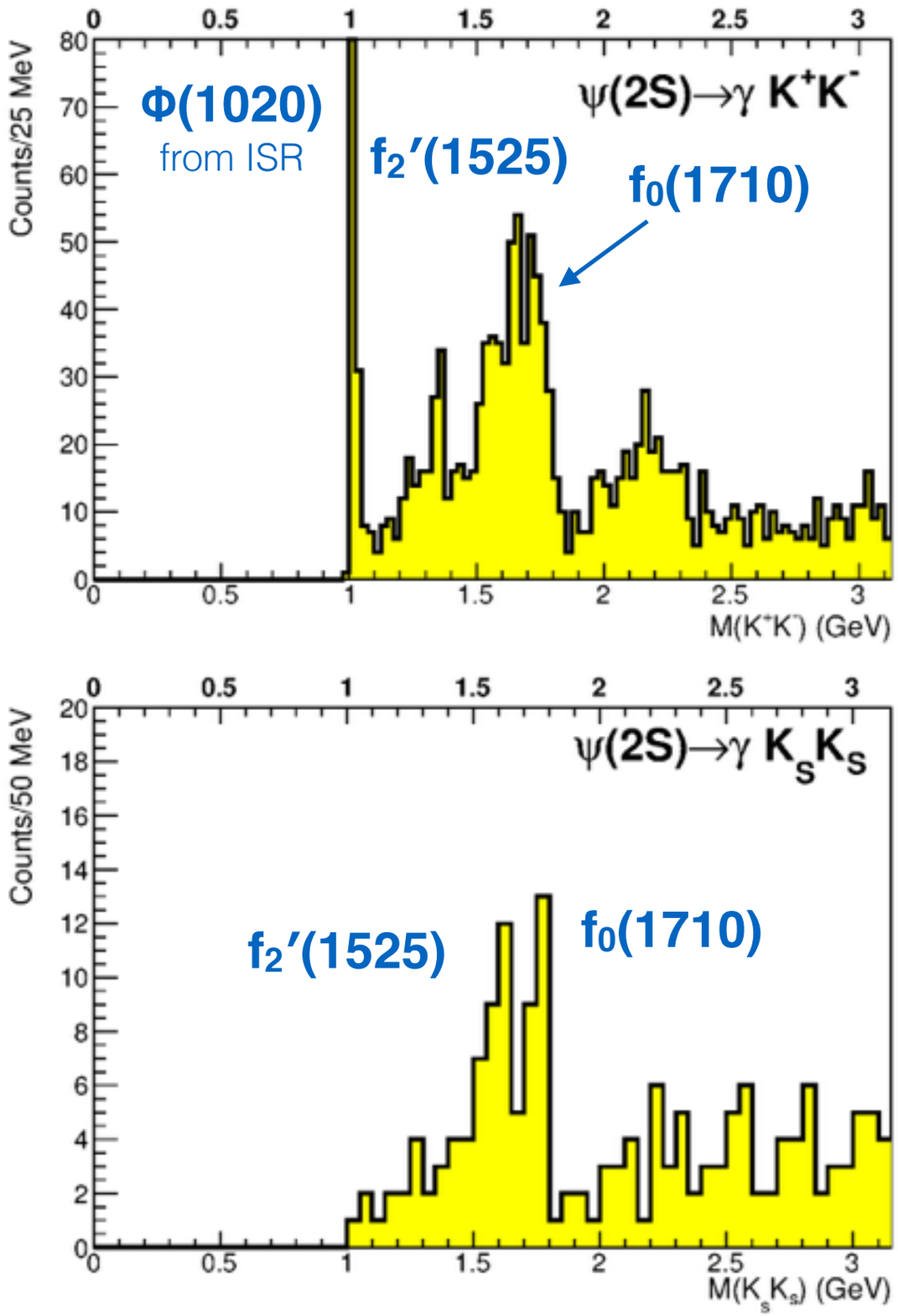
ππ Mass Spectra



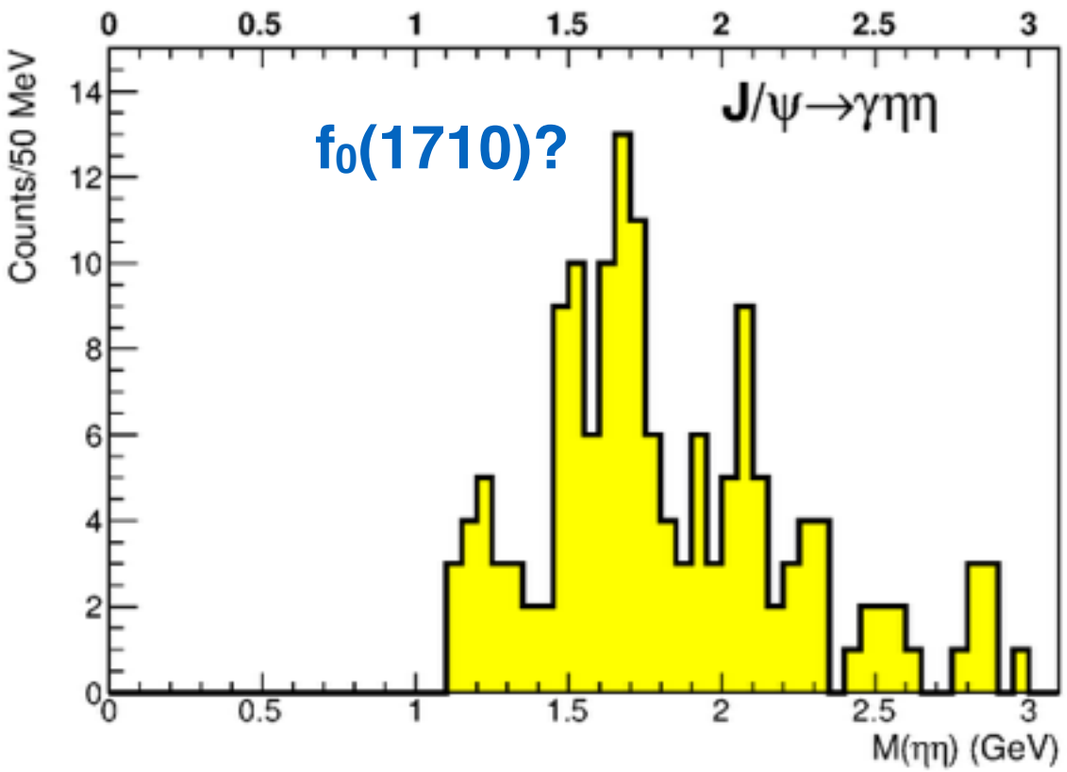


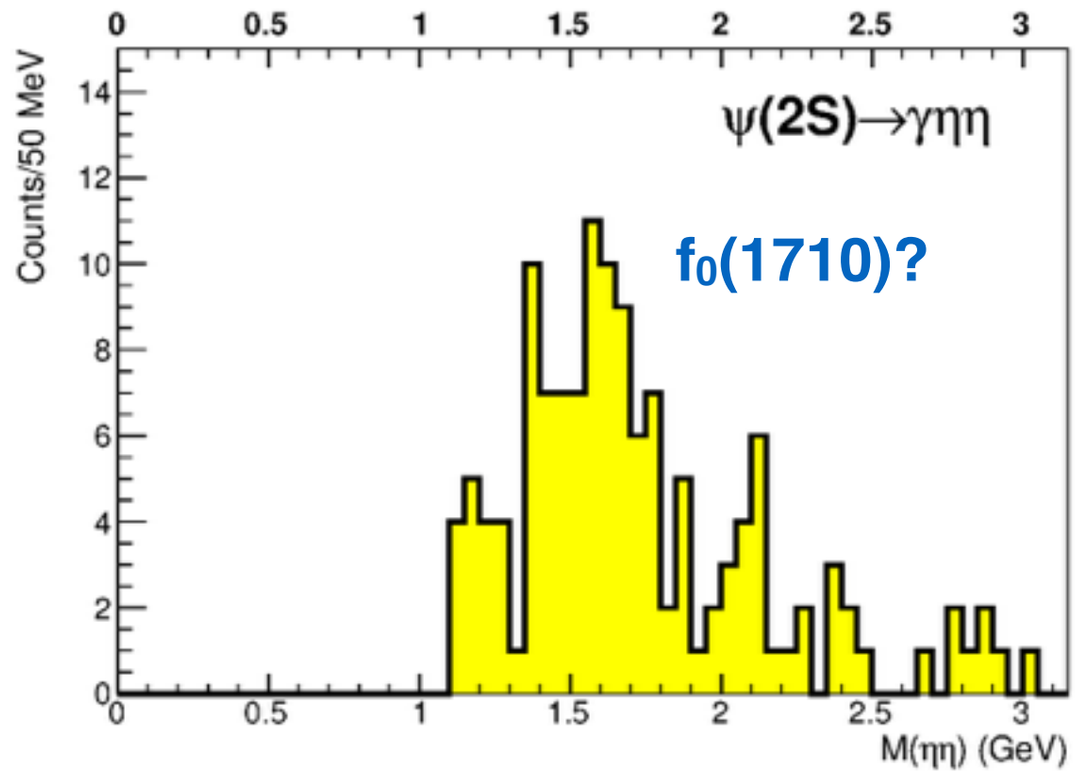
KK Mass Spectra





ηη Mass Spectra





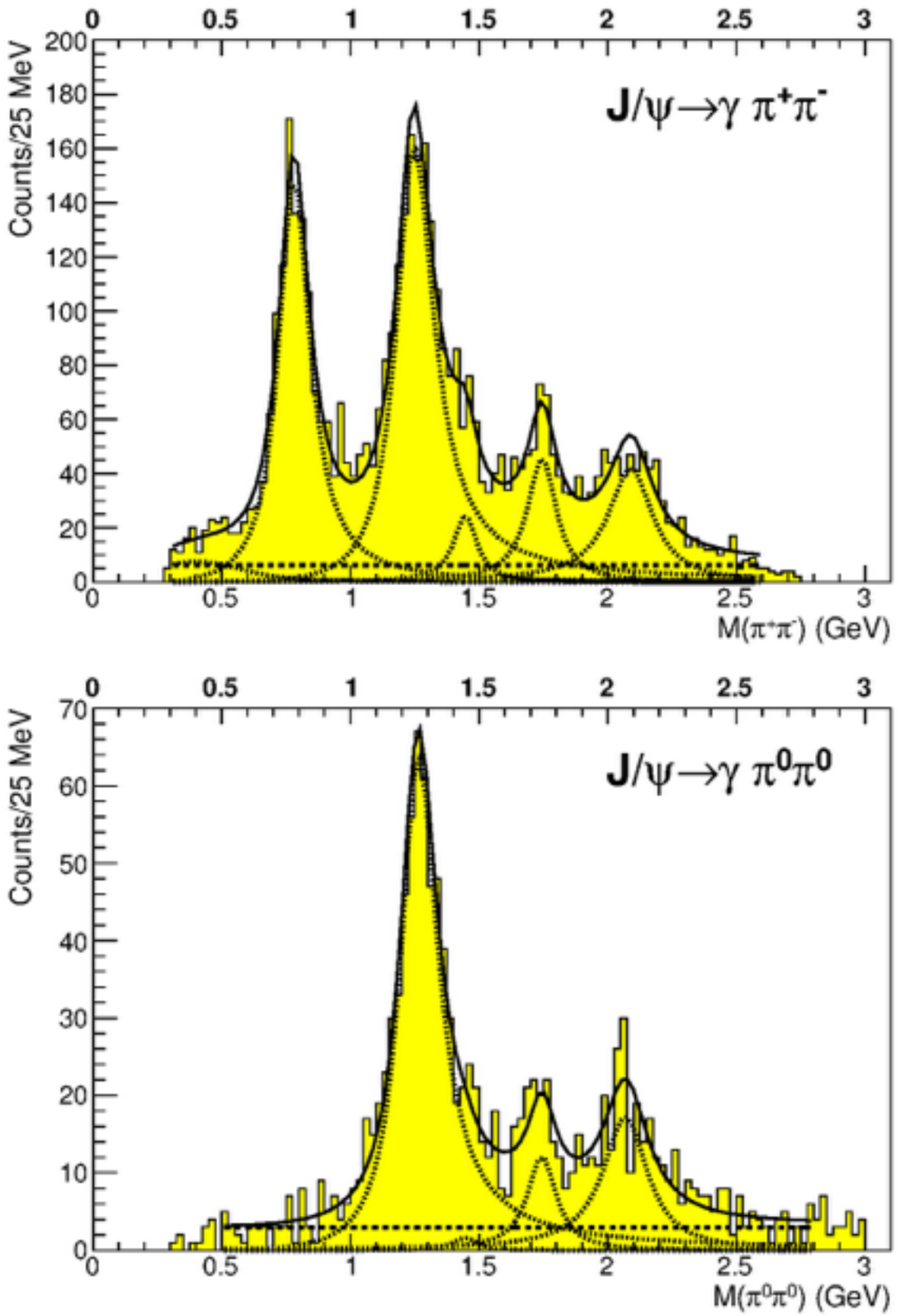
- Small statistics in ηη, only fit ππ and KK spectra.

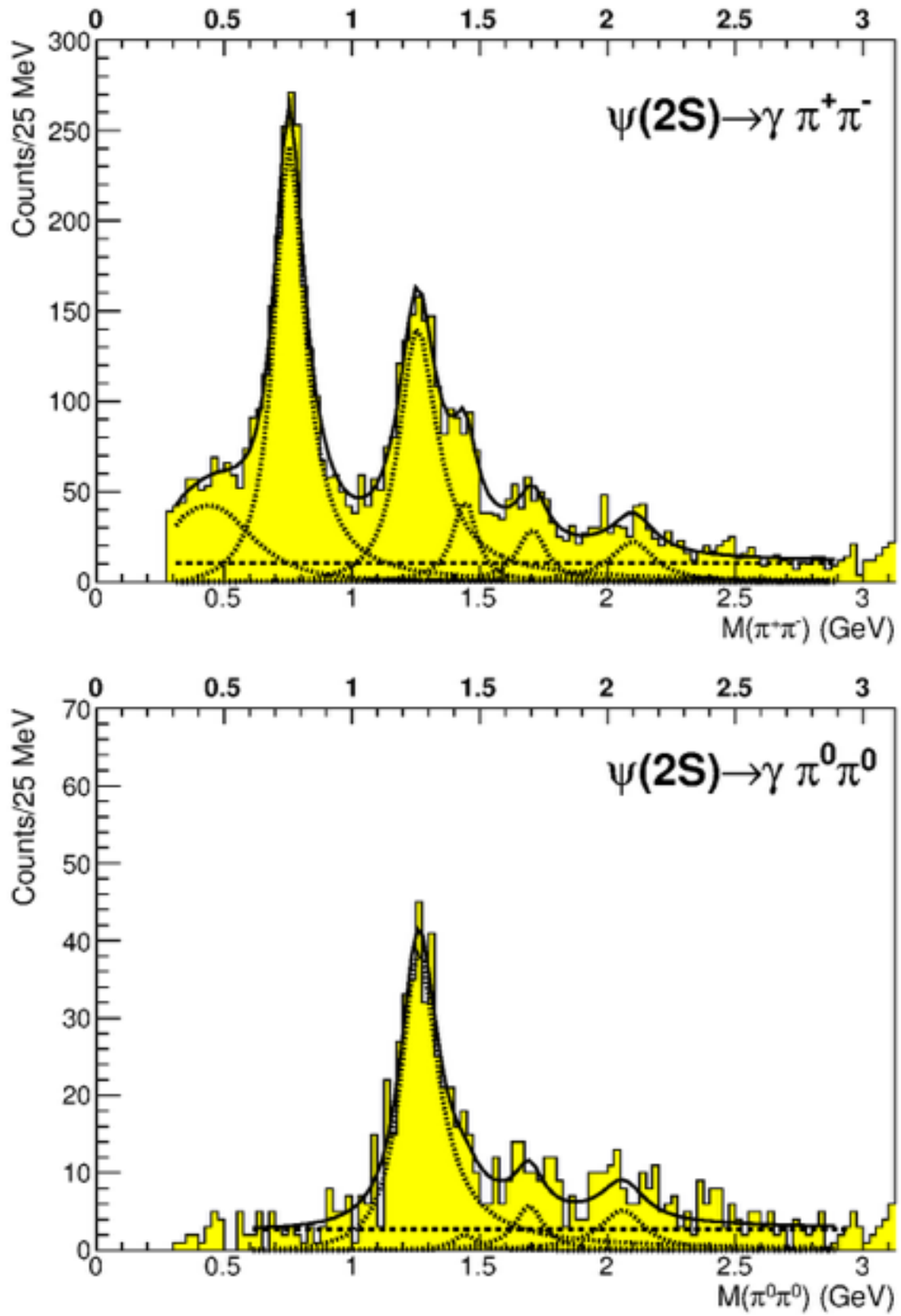
Fits to Mass Spectra

- We fit the mass spectra with relativistic, non-interfering Breit-Wigner shapes, and a constant or linear background.
  - **ππ**: ρ(770), f_2(1270), f_0(1500), f_0(1710), f_0(2100)
  - **KK**: f_0(1370), f_2'(1525), f_0(1710), f_0(2200)
    - Resonance widths fixed to PDG values. Mass and normalization float freely.

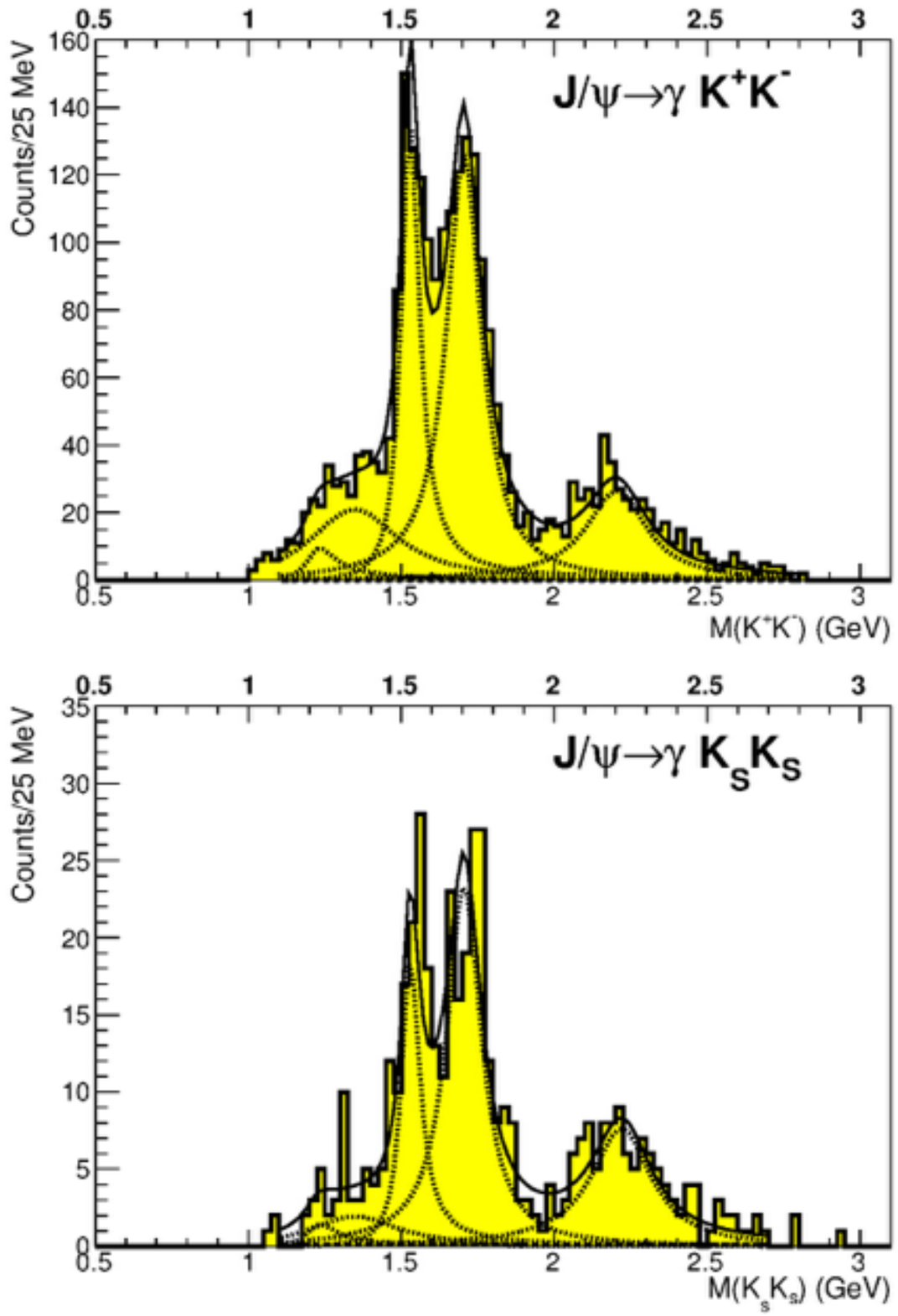
- Fit results are consistent between charged and neutral modes, also with simultaneous fits of charged and neutral spectra where isospin conservation is assumed.

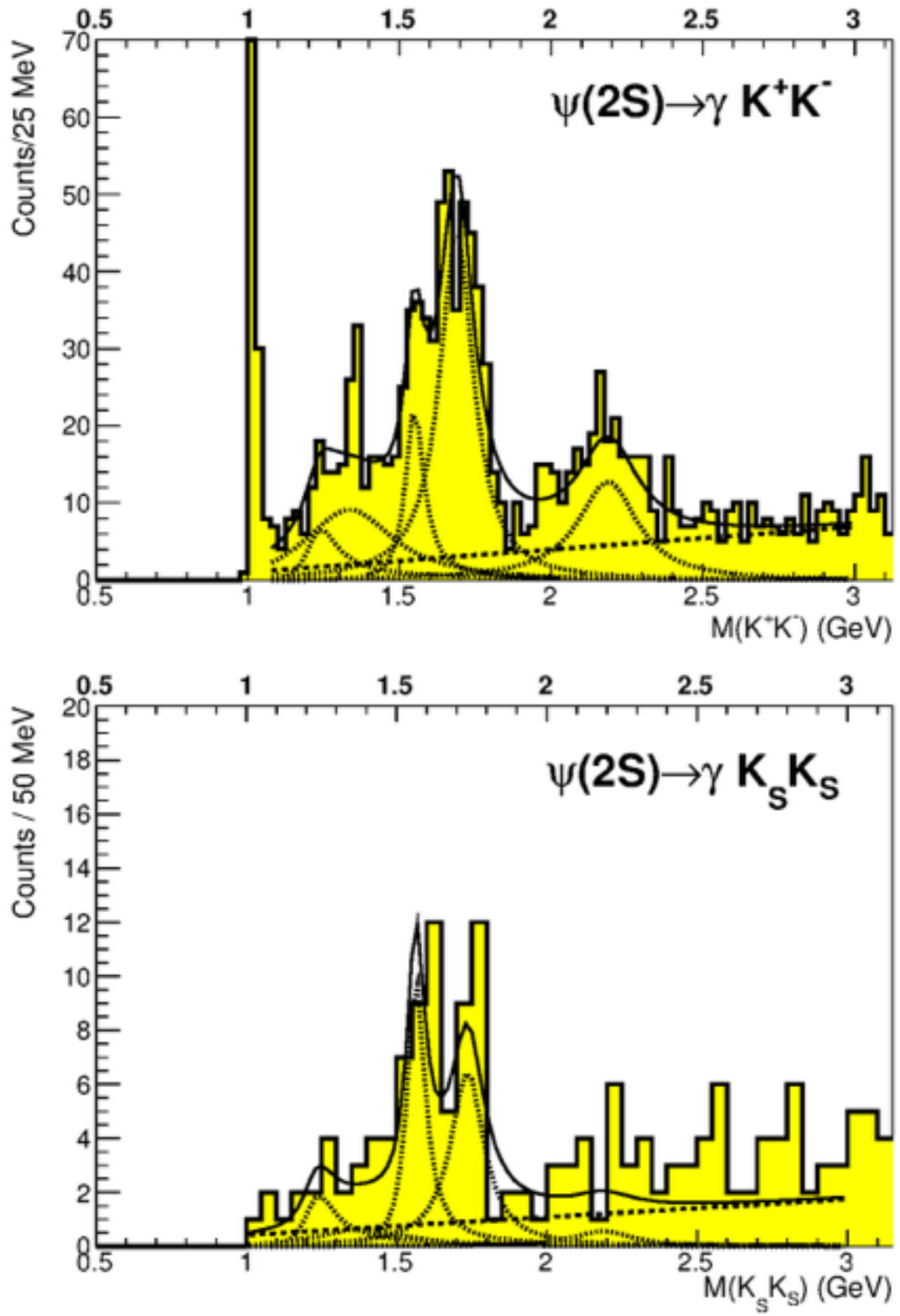
ππ Mass Spectra Fit Results





KK Mass Spectra Fit Results





Branching Fraction Results

	From J/ψ		From $\psi(2S)$		$\frac{\mathcal{B}_2(\psi(2S))}{\mathcal{B}_2(J/\psi)}$
	M (MeV)	$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^5$	M (MeV)	$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^5$	(%)
$f_2(1270) \to \pi\pi$	1259(4)(4)	174.4(52)(122)	1267(4)(3)	23.9(9)(9)	13.7(7)(11)
$f_0(1370) \to K\overline{K}$	1360(31)(28)	41.9(73)(134)	1350(48)(15)	3.1(10)(14)	7.4(27)(41)
$f_0(1500) \to \pi\pi$	1447(16)(13)	12.1(29)(24)	1442(9)(4)	3.2(6)(2)	26.4(80)(55)
$f_2'(1525) \to K\overline{K}$	1532(3)(6)	70.9(46)(67)	1557(9)(3)	2.9(6)(3)	4.1(9)(6)
$f_0(1710) \to \pi\pi$	1744(7)(5)	37.2(30)(43)	1705(11)(5)	3.6(4)(5)	9.7(13)(18)
$\to K\overline{K}$	1706(4)(5)	117.6(54)(94)	1690(8)(3)	6.7(6)(6)	5.7(6)(7)
$f_0(2100) \to \pi\pi$	2090(10)(6)	62.4(48)(87)	2099(17)(8)	4.8(5)(9)	7.7(10)(18)
$f_0(2200) \to K\overline{K}$	2206(12)(8)	58.6(49)(120)	2188(17)(16)	3.2(6)(8)	5.5(11)(18)

- Masses are generally consistent with PDG values.
- Branching fractions generally consistent with those measured by BES II PWA analyses.

Branching Fraction Results

	From J/ψ		From $\psi(2S)$		$\frac{\mathcal{B}_2(\psi(2S))}{\mathcal{B}_2(J/\psi)}$
	M (MeV)	$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^5$	M (MeV)	$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^5$	(%)
$f_2(1270) \to \pi\pi$	1259(4)(4)	174.4(52)(122)	1267(4)(3)	23.9(9)(9)	13.7(7)(11)
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$f_0(2200) \to K\overline{K}$	2206(12)(8)	58.6(49)(120)	2188(17)(16)	3.2(6)(8)	5.5(11)(18)

- Measured the ratio of $f_0(1710)$ decay to $\pi\pi$ and KK:

$$R = \frac{Br(f_0(1710) \to KK)}{Br(f_0(1710) \to \pi\pi)} = 3.2 \pm 0.4$$

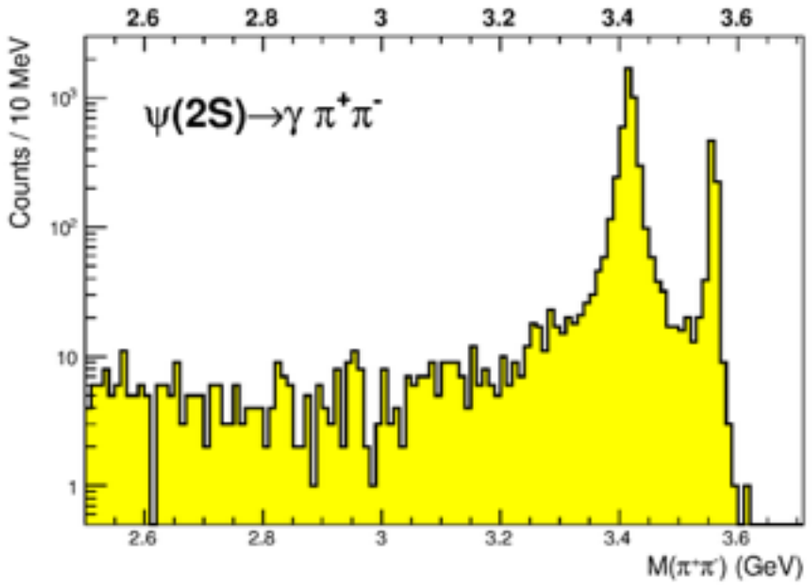
- Agrees with R(BES) = 2.9 ± 0.9, R(Mk. III) = $3.7\ ^{+1.6}_{-2.3}$
- Differs significantly from pure glueball expectation of 1.33. Useful to check different models of $f_0(1710)$ decay.

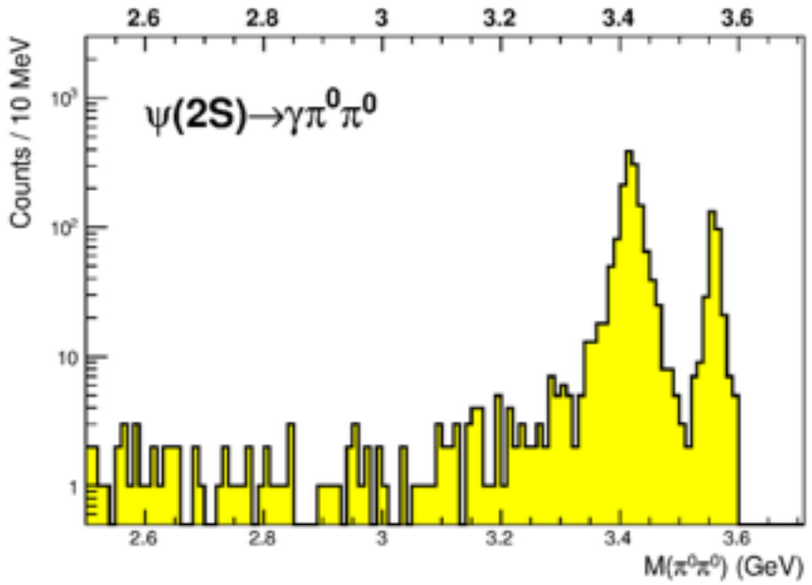
Upper Limits for $f_2(2200)$ Production

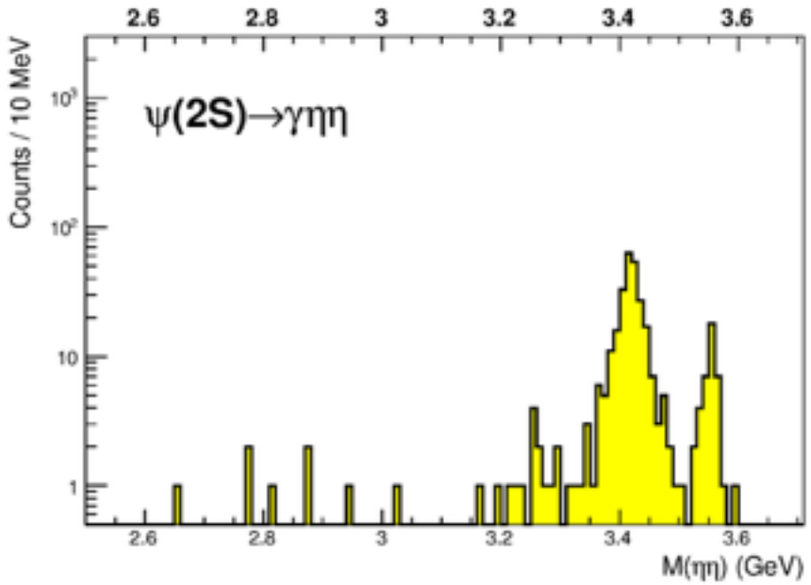
- The narrow $f_2(2200)$ has a long history of observations and non-observations.
- We do not observe this state, and set competitive upper limits on its production from J/ψ, first upper limits from ψ(2S).

		$\Gamma(\xi)$, MeV	90% CL UL N	90% CL UL $\mathcal{B}_1 \times \mathcal{B}_2$ $\times 10^5$	$\mathcal{B}_1 \times \mathcal{B}_2$ (ref.) $\times 10^5$
J/ψ	$\to \gamma(\pi^+\pi^-)$	20/50	23.0/45.1	2.6/5.2	$5.6(^{27}_{26})$ [18]
	$\to \gamma(\pi^0\pi^0)$	20/50	16.0/23.2	1.3/1.9	—
	$\to \gamma(K^+K^-)$	20/50	25.4/44.6	1.7/3.1	$3.3(^{16}_{13})$ [18], $4.2(^{19}_{16})$ [15] 2.3 (95% CL) [17]
	$\to \gamma(K^0_S K^0_S)$	20/50	11.5/19.1	1.2/2.0	$3.1(^{17}_{15})$ [18], $2.7(^{14}_{12})$ [15] 1.6 (95% CL) [17]
$\psi(2S)$	$\to \gamma(\pi^+\pi^-)$	20/50	22.9/31.1	0.32/0.43	—
	$\to \gamma(\pi^0\pi^0)$	20/50	15.7/23.6	0.26/0.40	—
	$\to \gamma(K^+K^-)$	20/50	18.9/38.0	0.21/0.43	—
	$\to \gamma(K^0_S K^0_S)$	20/50	10.7/15.6	0.37/0.55	—

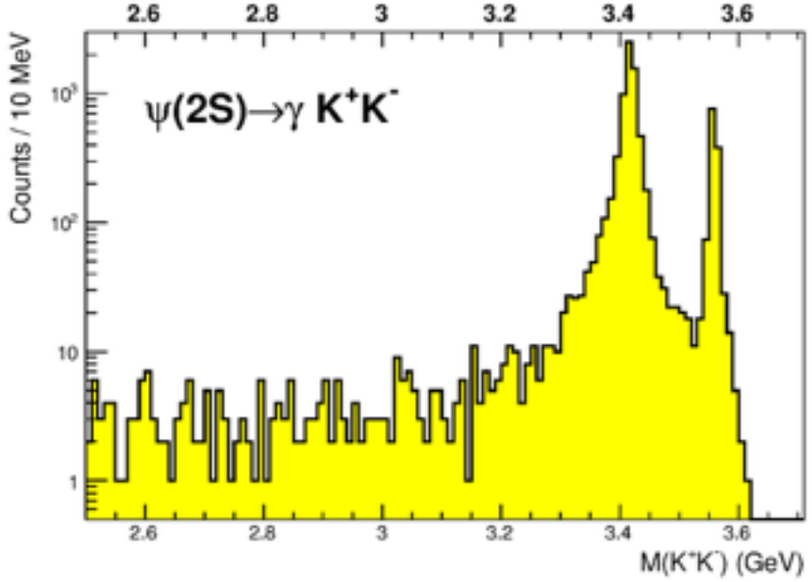
χ_{cJ} Mass Spectra

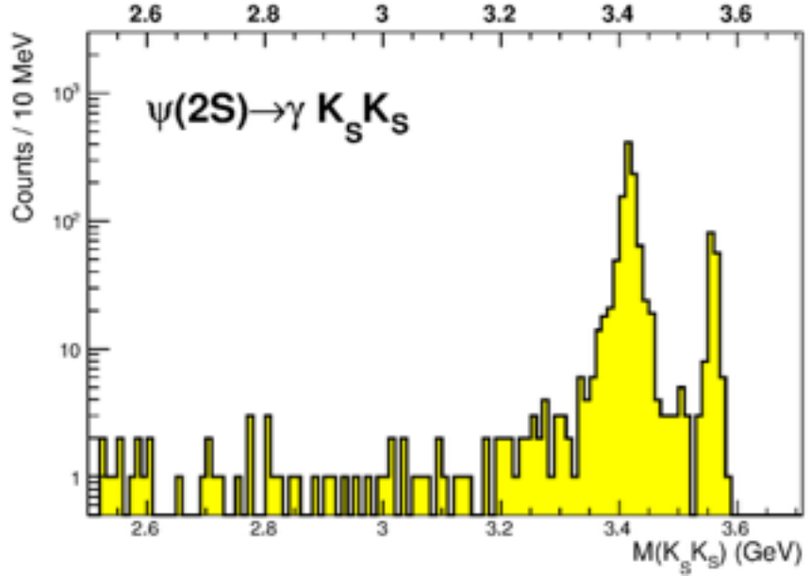






- Clear signals seen for two pseudoscalar decay of χ_{cJ} states.





- Branching fractions consistent with PDG values and previous CLEO publications.

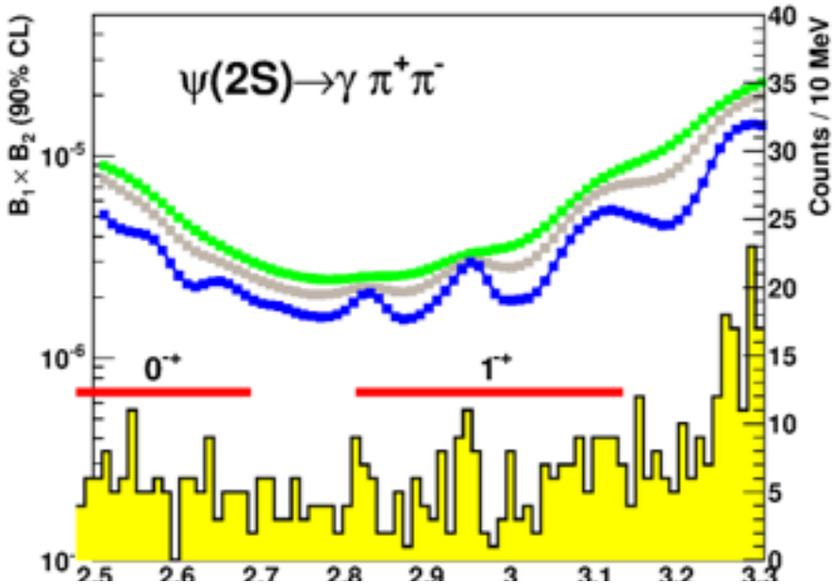
χ_{cJ} Branching Fraction Ratios

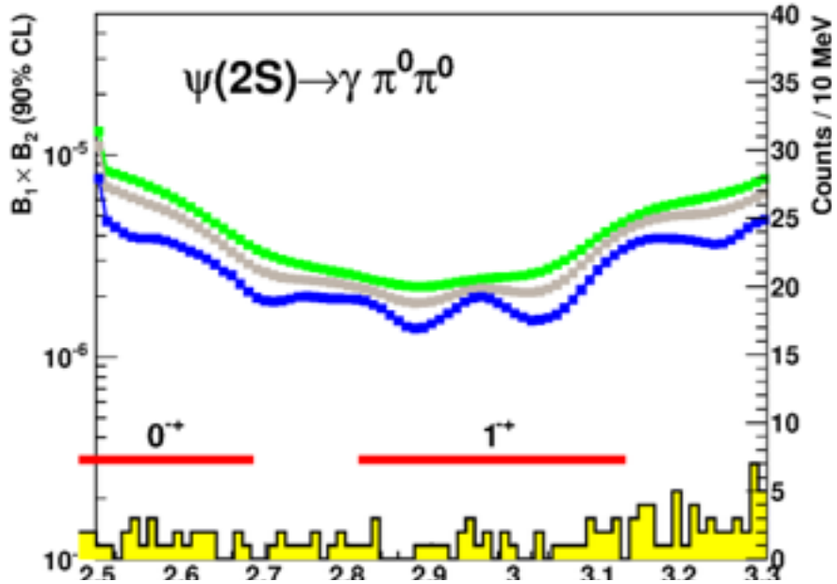
- Ochs [J.Phys.G.Nucl.Part.Phys. 40, 04301 (2013)] has pointed out that the χ_{c0} and χ_{c2} decays are mediated by 2 gluons, and thus provide an opportunity to test the flavor independence of these decays.
- CLEO-c data are consistent with the theoretical expectations, except $\eta'\eta'$ decays.

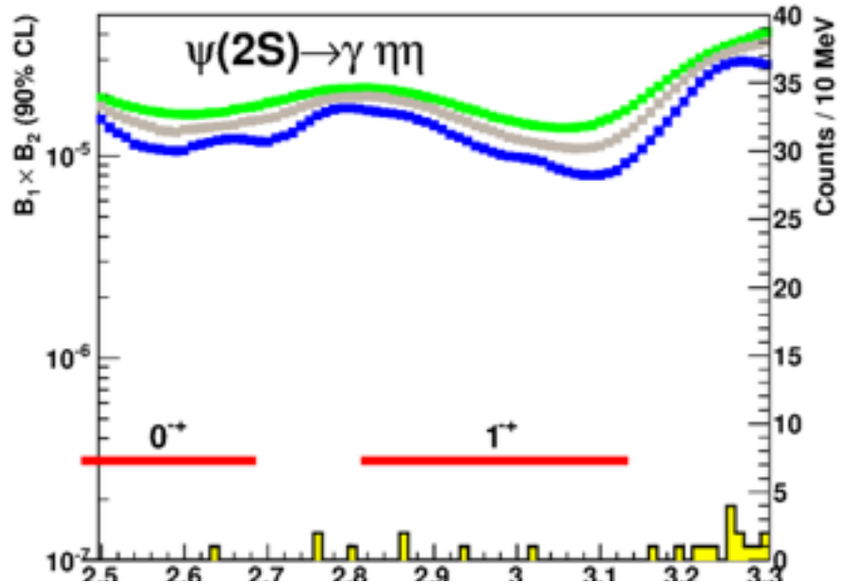
[see also PRD 75, 071101(R) (2007), PRD 79, 072007 (2009)].

Pseudoscalar pairs	$\pi\pi$	$K\overline{K}$	$\eta\eta$	$\eta'\eta'$	$\eta\eta'$
Two-gluon decays (theoretical)	$=1$	1.33	0.33	0.33	0
χ_{c0} decays	$=1.00(5)$	1.41(6)	0.34(4)	0.23(3)	0.02(1)
χ_{c2} decays	$=1.00(5)$	0.98(6)	0.23(4)	0.025(15)	0.006(15)
χ_{c0} decays (divided by phase space factor p)	$=1.00(5)$	1.47(9)	0.36(4)	0.27(3)	0.02(1)
χ_{c2} decays (divided by phase space factor p^5)	$=1.00(5)$	1.18(8)	0.28(4)	0.058(34)	0.010(22)

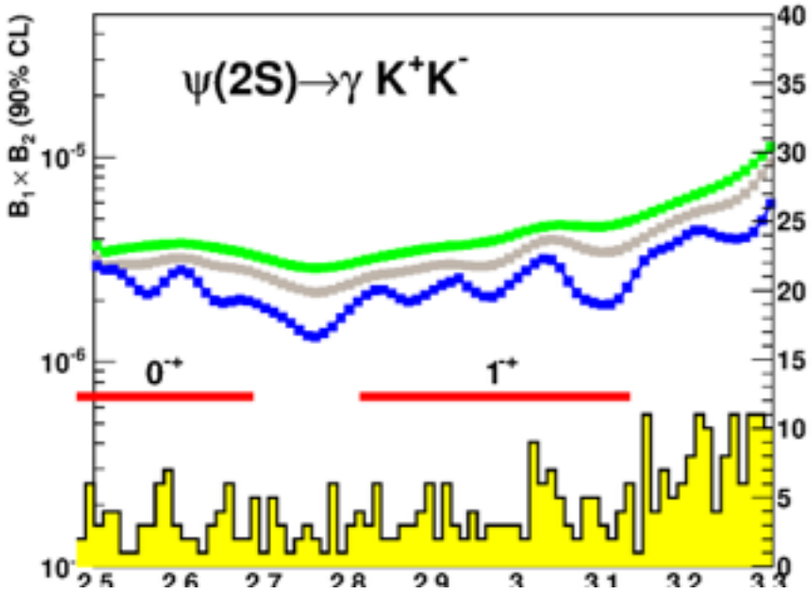
Upper limits on higher mass glueball production

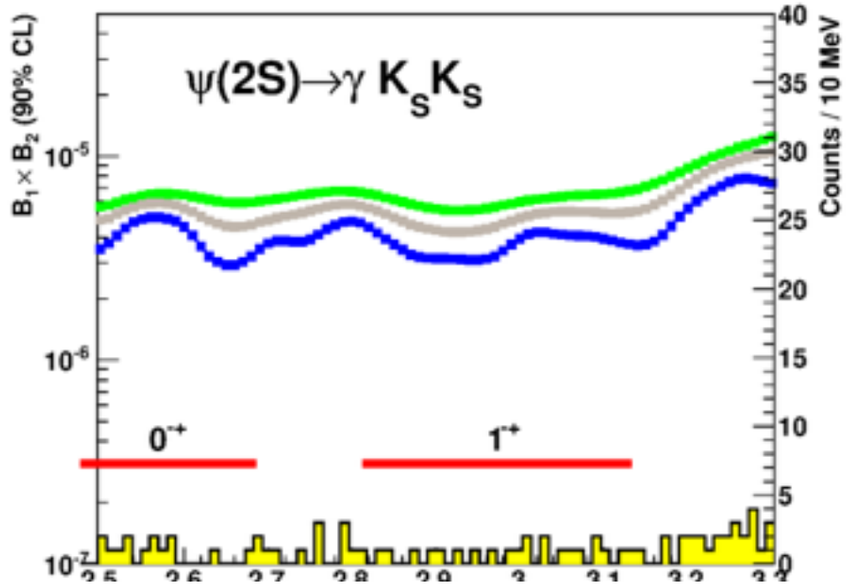






- No evidence seen for peaks with widths of 10 - 100 MeV, in mass region below χ_{cJ} peaks.





- Upper limits on the productions of such states were determined.

Summary

- We analyzed 25 M ψ(2S) and 5M J/ψ of CLEO-c data for the reaction

  $J/\psi, \psi(2S) \rightarrow \gamma + [\pi^+\pi^-, \pi^0\pi^0, K^+K^-, K_SK_S, \eta\eta]$

  - Results published as PRD 91, 052006 (2015). ψ(2S) results are the world's first.

- Branching fractions for radiative decays to scalar and tensor mesons were measured.

  - The measured ratio $R(f_0(17100))_{\pi\pi/KK} = 3.2$ gives insight into its composition.

- No evidence for the narrow tensor glueball or higher mass glueballs was seen, upper limits on their production were established.

Backup Slides

Basic Event Selections

Decay Mode		# tracks	# showers
$\psi(2S) \rightarrow$	$\gamma\,\pi^+\pi^-$	2	≥ 1
	$\gamma\,K^+K^-$	2	≥ 1
	$\gamma\,\pi^0\pi^0$	0	≥ 5
	$\gamma\,\eta\eta$	0	≥ 5
	$\gamma\,K_SK_S$	≥ 4	≥ 1
$J/\psi \rightarrow$	$\gamma\,\pi^+\pi^-$	4	≥ 1
	$\gamma\,K^+K^-$	4	≥ 1
	$\gamma\,\pi^0\pi^0$	2	≥ 5
	$\gamma\,\eta\eta$	2	≥ 5
	$\gamma\,K_SK_S$	≥ 6	≥ 1

Background Studies